An Environmental Examination Of Sedimentation In Lindisfarne Bay

by J. M. WOOD
Dip. App. Sc. (Env. Health)

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Centre for Environmental Studies
Department of Geography and Environmental Studies
University of Tasmania
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STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university , and to the best of my knowledge contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text.

Jamie Wood
University of Tasmania
December 1988

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ABSTRACT

Lindisfarne Bay is one of several small estuarine bays on the eastern side of the lower Derwent Estuary near Hobart in southeastern Tasmania. It once contained sandy beaches and was originally known as Beauty Bay being used as a place for recreational pursuits by residents of Hobart early after European settlement.

Concomitant with urbanisation of the catchment, industrial activities, and indiscriminate land use practices has been the problem of sedimentation. Attempts to redress the situation have included land reclamation and public pressure to replace sand on the beaches.

This study aims to quantify the extent of sediment deposition in Lindisfarne Bay and to identify sources of sediment from within the catchment by using the caesium radionuclide tracing and dating technique, by examining levels of heavy metals in the deposited sediment, and by relating these to the land use history of the Bay and estuary.

Core samples were taken to a depth of up to 1.4 m from eight sites around the intertidal zone of the head of the bay by using a purpose-built coring device. These cores have been analysed for caesium-137 (^{137}Cs) activity, heavy metal content (cadmium, copper, lead and zinc), and grain sizes of sediments. Sediment deposition rates are determined to be between 2.7 and 3.3 cm yr^{-1} by ^{137}Cs analyses. Heavy metal concentrations indicated sedimentation rates compatible with ^{137}Cs results and maximum levels at depths of 0.5 to 1.0m. Grainsize analyses formed an important part of the interpretation of sediment dynamics within the Bay by showing significantly different proportions of mean grainsize between the eastern side and the western side of the head of the Bay.

An input of reference value for the average areal activity of ^{137}Cs for the region was established to be 77.6 mBq cm^{-2}. The source of sediments has been alluded to by further areal activities of ^{137}Cs distribution in the catchment. Natone Hill emerged as a principal source of sediments.

Before management options can be considered, it is argued that a sound knowledge of the sedimentation problem should be gained. Such an understanding has been achieved and laid a foundation for appropriate management practices such as minimising sediment escape from the catchment by reviewing the burning regime of Natone Hill and Gordons Hill, forbidding the use of off-road vehicles on Natone Hill, and minimising run-off from road sites as well as installing silt traps to major storm water outlets.

Phasing out of Ministerial exemptions from the Environment Protection Act 1973 for sewage treatment plants along the lower Derwent Estuary and the Electrolytic Zinc Company of Australasia Limited is imperative for improving water quality and heavy metal loading to sediments within the bay. Once the necessary steps have been taken to prevent further sedimentation and pollution, a program of dredging and foreshore beautification could be implemented.

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CHAPTER 1

INTRODUCTION

1.1 The Estuarine sedimentation problem

Estuaries are semi-enclosed coastal bodies of water which have free connections with the open sea and within which seawater is measurably diluted with fresh water from land drainage (Pritchard 1967). Estuaries are typified by complex interactions between salt and fresh water, and form major fish nurseries (Dyer 1979).

From a geomorphological point of view, estuaries may be subdivided into four main categories: (1) drowned river valleys, (2) fjord-type estuaries, (3) bar-built estuaries and (4) estuaries produced by tectonic processes (Pritchard 1967). Drowned river valleys are widespread throughout the world and are the most common type of estuary. Fjord-type estuaries are generally U-shaped and have been gouged out by glaciers leaving sills and deep basins. Bar-built estuaries are formed when off-shore barrier sand islands and sand spits build above sea-level and extend between headlands in a chain, broken by one or more outlets.

When classifying estuaries the three basic processes of wind, tidal movement and river water should be considered (Bowden 1967). In a tidal dominated estuary such as the Derwent Estuary, turbulence associated with tidal currents results in mixing between salt water and fresh water.

The role played by tidal currents relative to that of river flow is an important factor in determining the type of circulation occurring in an estuary. Other factors include the physical dimensions of the estuary and the effect of the earth's rotation on the Coriolis force (Bowden 1967).

In the estuarine environment fluviatile fresh water, with a salinity of approximately 0.001 percent of total weight, encounters the marine salt water environment with a salinity of 3.5 percent of total weight. This difference in salinity results in layering of the two water bodies and thereby influences the mechanisms of sedimentation, precipitation and flocculation of particulate substances, as well as many biological processes. Bowden (1967) identified four types of estuarine circulation. He stated however that two layer flow with vertical mixing appeared to be the major system of circulation. Bowden also stated that the fresh water moved downwards as the more saline water moved upwards resulting in a salinity profile which increased continuously from surface to bottom. Apparently the layering of different water bodies also affects the transport characteristics of sediments in estuarine areas.

One characteristic of estuaries is their vulnerability to human influence. They often lie in proximity to population centres and are 'doorways' between the ocean and the land mass (Eugene Cronin 1967). The worldwide effects of people on estuaries has been evident since the enormous increase in human population during the last century. Of the ten largest metropolitan areas in the world, seven border estuarine areas (Tokyo, New York, London, Shanghai, Buenos Aires, Osaka and Los Angeles). In fact, one third of the population of the United States of America lives and works close to estuaries (Eugene Cronin 1967).

The historical development of land has also been closely linked with estuaries. Therefore it is appropriate to identify and consider how, as land masses have been explored and populations have grown, fundamental changes have taken place in estuarine processes. For example, in North America, the history of exploration, colonisation and settlement of the coasts illustrates how estuaries have been used in the development of new population centres. Although human activity probably had little significant effect on estuaries prior to about 1850 and was limited to such factors as silt erosion from agricultural areas and disposal of human wastes (Eugene Cronin 1967), the enormous increase during the last century of industrial activity and production, the use of power, and the diversity of manufactured materials and transportation have all played significant roles in changing estuarine interactions. In Australia, the concentration of the population in coastal regions has similarly altered the natural processes occurring in estuaries.

As human activity around estuaries has increased with time there have been concomitant changes in freshwater inflow. Obviously, the construction of dams or the diversion of river water for human consumption can decrease the flow of fresh water in estuaries. Conversely, flow can be significantly increased in the drainage basin as a result of vegetation clearance or by decreasing the infiltration and subsurface retention of water by providing paved areas, houses and roads in urban areas.

Associated with these hydraulic changes is the problem of sedimentation.According to Beer (1983), there are seven possible sources of sediment within an estuary:

(a) land erosion by rivers and streams;.

(b) disposal of domestic and industrial effluents and solid wastes;

(c) littoral drift and bank erosion;

(d) wind erosion of coastal dunes and drying of intertidal shoals;

(e) erosion of near shore continental shelf;

(f) return of dredged spoil; and

(g) decomposition of excrements of marine and river flora and fauna.

Sedimentation of estuaries can occur with or without the influence of humans. Natural factors include deposition of sediments by run-off due to the breakdown of rocks within the local catchment, deposition of material carried downstream by the river and particles derived from the nearby sea-bed. On the other hand, deforestation and poor agricultural practices are major human-induced factors. Sediments deposited by run-off from the catchment may also contain material from the urban environment, e.g., road gravels and garden soils. Although these and other non-point sources contribute significantly to the problem of sedimentation in estuaries, they have received little attention by researchers.

A great number of estuarine sedimentation investigations have been carried out in marine coastal areas particularly looking at the effects of heavy metal pollution (Forstner & Wittmann 1981). These studies have made it clear that estuaries are a problem area, especially in heavily polluted and industrialised regions where large amounts of waste material containing heavy metals are transported by rivers to meet the near-coast marine systems. In fact, Forstner & Wittmann (1981) compiled a table of the maximum metal concentrations occurring in sediments which showed that the six regions in the world most heavily polluted by heavy metals were all estuaries (Table 1.1).

Table 1.1 Maximum metal concentrations in sediments from bays & estuaries (all values in ppm)

Source	*Cadmium*	*Copper*	*Lead*	*Zinc*
Average shale	0.3	45	20	95
Rio Tinto Estuary (Spain)	4.1	1400	1600	3100
Restronguet Estuary (UK)	12	4500	1620	3000
Acushnet Estuary (UK)	76	7500	560	2300
Corpus Christi Bay (USA)	130	-	-	1100
Sorfjord (Norway)	850	1200	30500	118000
Derwent Estuary (Tasmania)	862	-	1000	10000

(Cited in Forstner & Wittmann 1981)

It should be noted that Forstner & Wittmann (1981) cite the Derwent Estuary as one of the most polluted estuaries viewed (Table 1.1).

1.2 Lindisfarne Bay : A sedimentation problem in the Derwent Estuary, southeastern Tasmania.

Estuaries and estuarine beaches are conspicuous features of the Australian coastline. The Derwent Estuary in southeastern Tasmania is a drowned river valley and has a tidal-dominated mixing mechanism resulting in a classical salt water-freshwater wedge (Thompson & Godfrey 1985).

Lindisfarne Bay is one of several small estuarine bays on the eastern side of the Derwent Estuary (Fig 1.1). The waters of the bay (Fig 1.2) cover an area of approximately half a square kilometre and are controlled by the Marine Board of Hobart. The catchment of the bay lies in the Clarence Municipality and covers an area of approximately three square kilometres. The Hobart suburb of Lindisfarne encompasses most of the lower land area within the catchment. Stretches of undeveloped land remain above the 50m contour on Natone Hill, above the 70m contour on Gordons Hill and on the summit of Pilchers Hill (Fig 1.3).

Lindisfarne Bay was of aesthetic and recreational significance to Hobart residents at the turn of the century (Plate 1.1). It was well known for its excellent beaches and clear waters. However, land development which commenced with colonisation, has rapidly changed the appearance of the Bay by altering the physical aspects of its foreshore. A comparison between Plates 1.2 and 1.3, taken c.1940 and in 1984 respectively, clearly indicates these changes. This has been most evident since 1945. Lindisfarne Bay has become polluted and, due to a massive accumulation of sediment, beaches have virtually disappeared. As well, the greater amounts of leisure associated with improved social and working conditions have led to an enormous increase in outdoor leisure based activities. In an estuarine city such as Hobart, many of these activities have been focused on the foreshores, the beaches and on the Derwent River itself. Consequently, there has been a growing awareness of and concern about deterioration of such outstanding environments as the water front. As a result, local governments and the community generally have responded in an attempt to address the problems confronting the Derwent Estuary. Two of these responses have directly affected Lindisfarne Bay.

Firstly, the Derwent River Management Plan (Hepper, Marriot & Associates 1985) was commissioned by local authorities bordering the Derwent River. This was an ambitious and creative attempt to guide the management of the Derwent River and environs and thus, enhance it for the long term beneifit of the community. Major recommendations included management of the river and its foreshores as a public asset; provision for resolving land use activity disputes; a better quality of development; and the establishment of practices that could

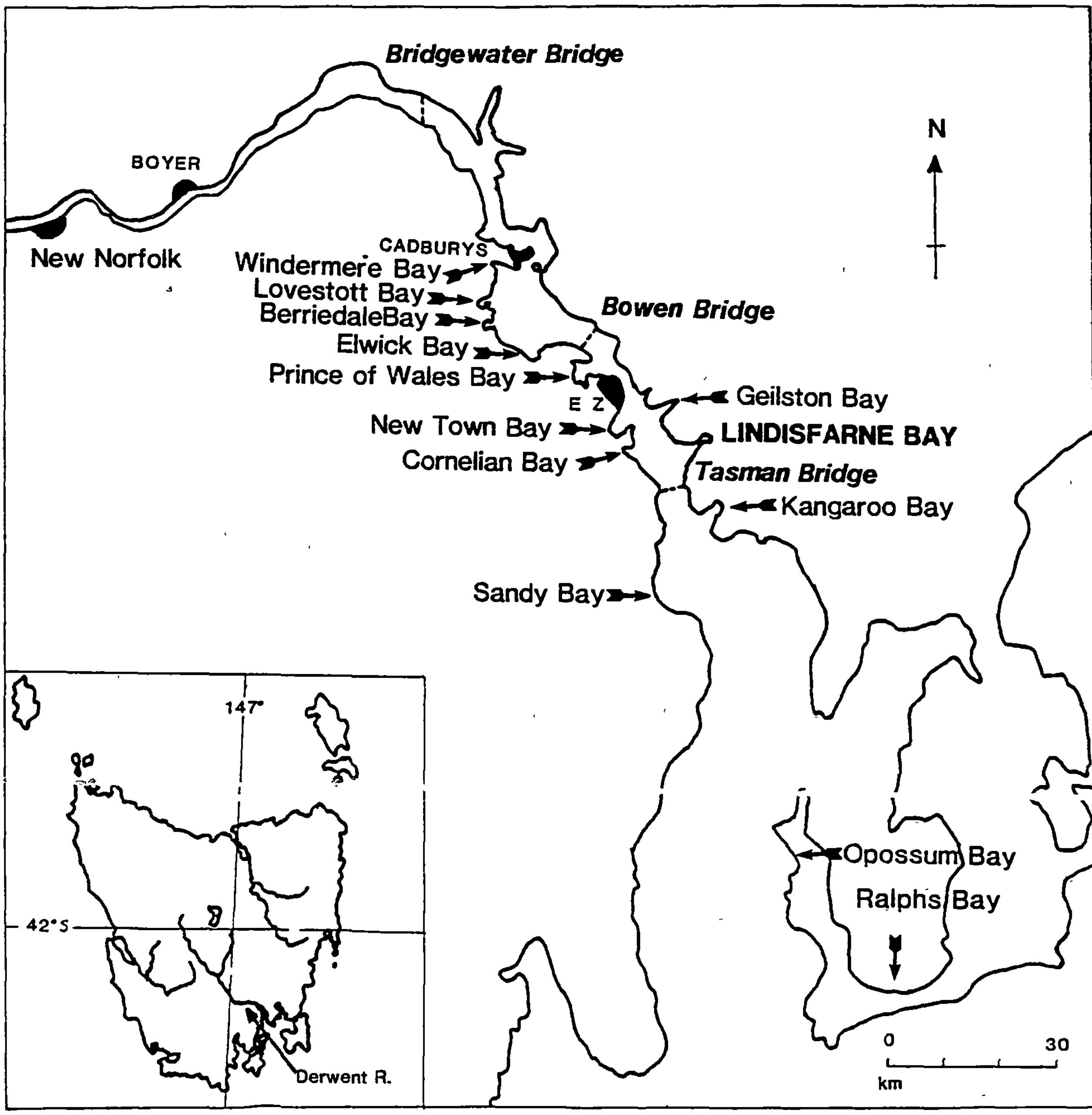

Fig. 1.1 Derwent Estuary

The Derwent Estuary stretches from the town of New Norfolk to past Opossum Bay. Industries along the estuary include the Australian Newsprint Mills at Boyer, Cadbury's chocolate factory and the Electrolytic Zinc Company of Australasia Ltd. (EZ); three road crossings traverse the estuary

source: Lands Department Tasmania

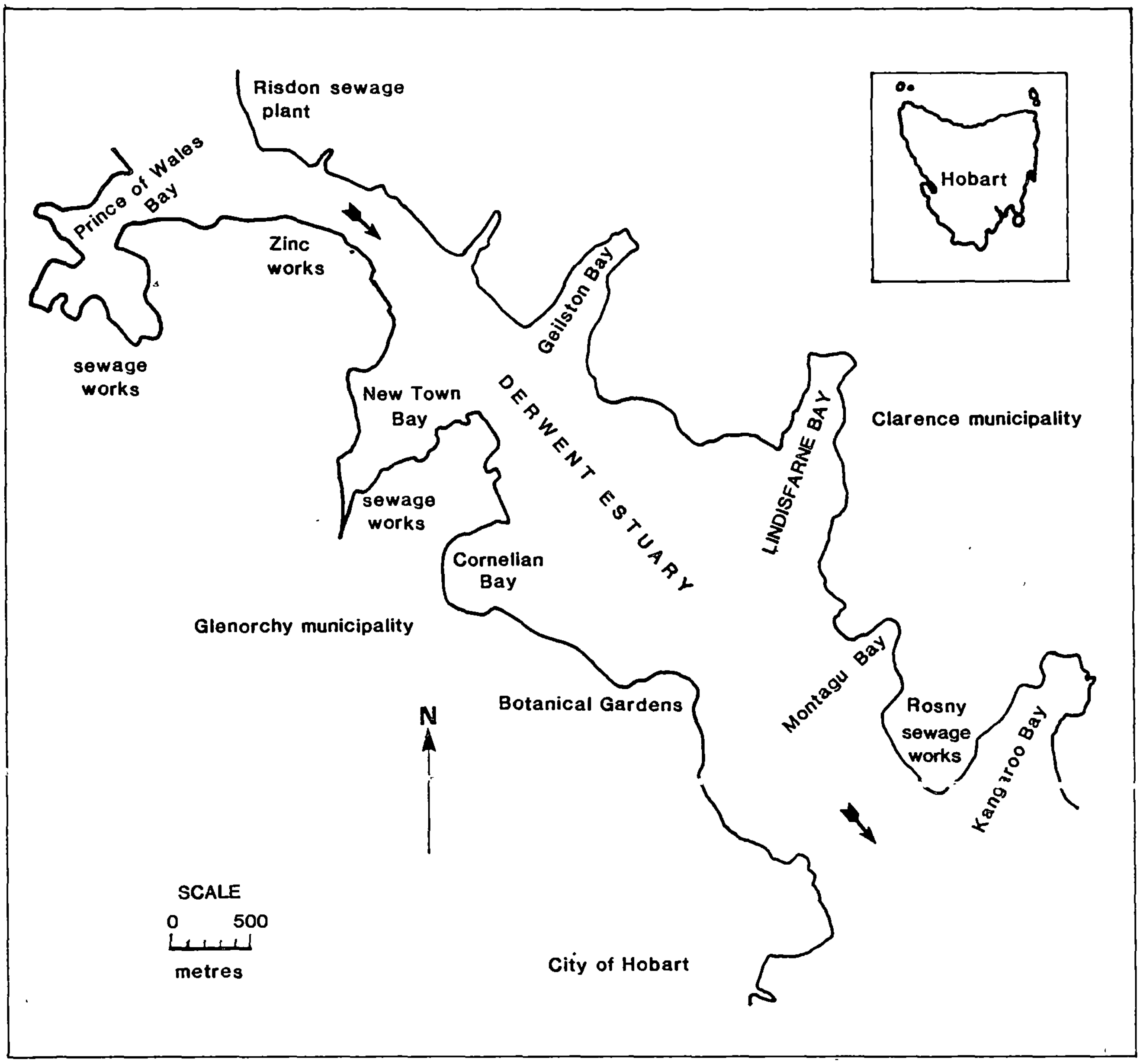

Fig 1.2 Lindisfarne Bay in the lower Derwent Estuary

source: Department of Lands Tasmania, Tasmap - Hobart 5225, 1:25000 series

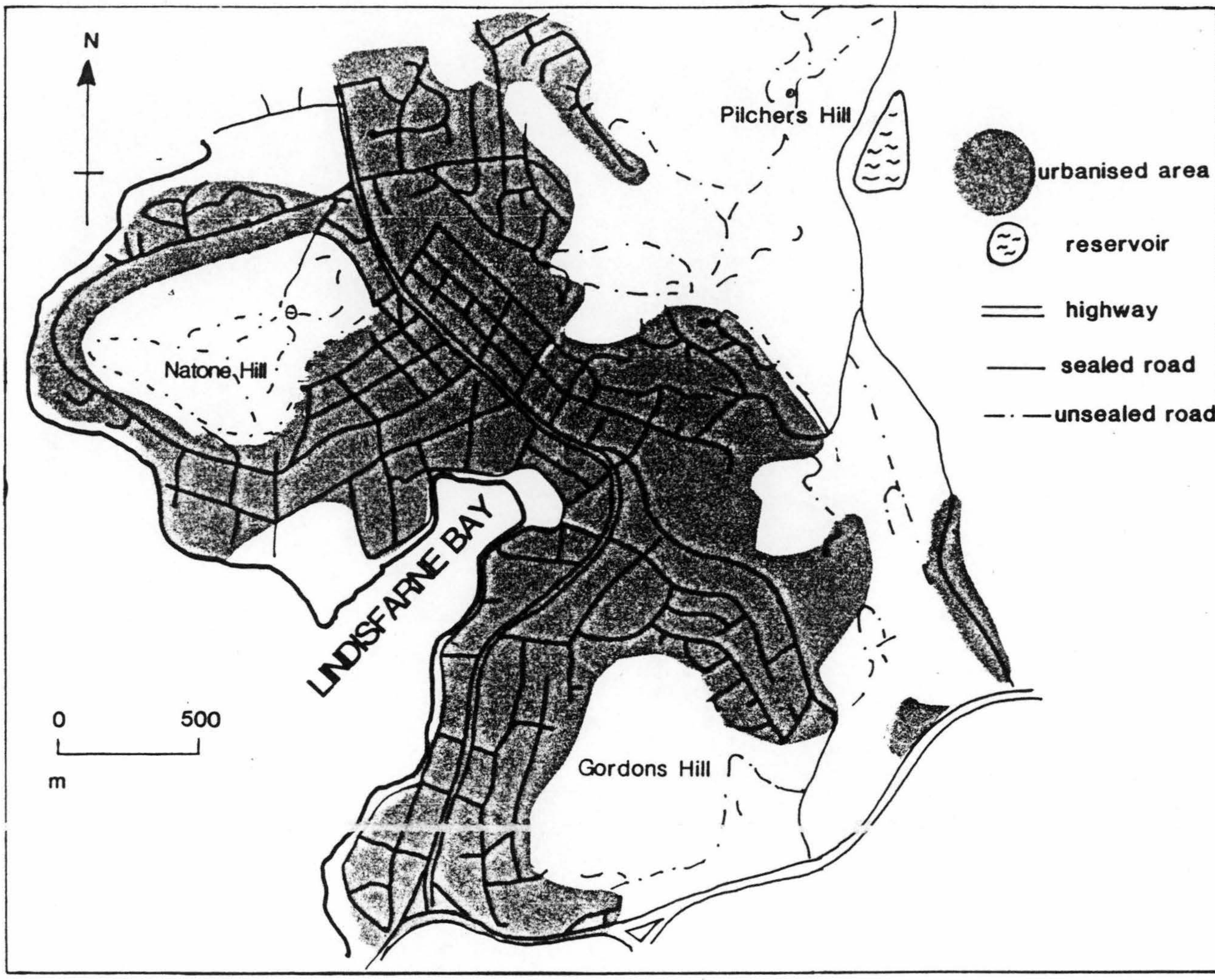

Fig. 1.3 Urbanisation of Lindisfarne

Note the undeveloped land on Natone Hill, Gordons Hill and Pilchers Hill. Natone Hill and Pilchers Hill feature a series of off-road vehicle tracks; Gordons Hill is a State Reserve under the control of the Tasmanian Department of Lands, Parks & Wildlife; an extensive roading system caters for the urban area

source: Department of Lands Tasmania, Tasmap - Hobart 5225, 1:25000 series

Plate 1.1 People on foreshore, Lindisfarne Bay 1900 - 1914

The white fence in the background features in Plate 2.1 indicating that this photograph was taken on the eastern side of the bay

source: Tasmanian State Library Archives

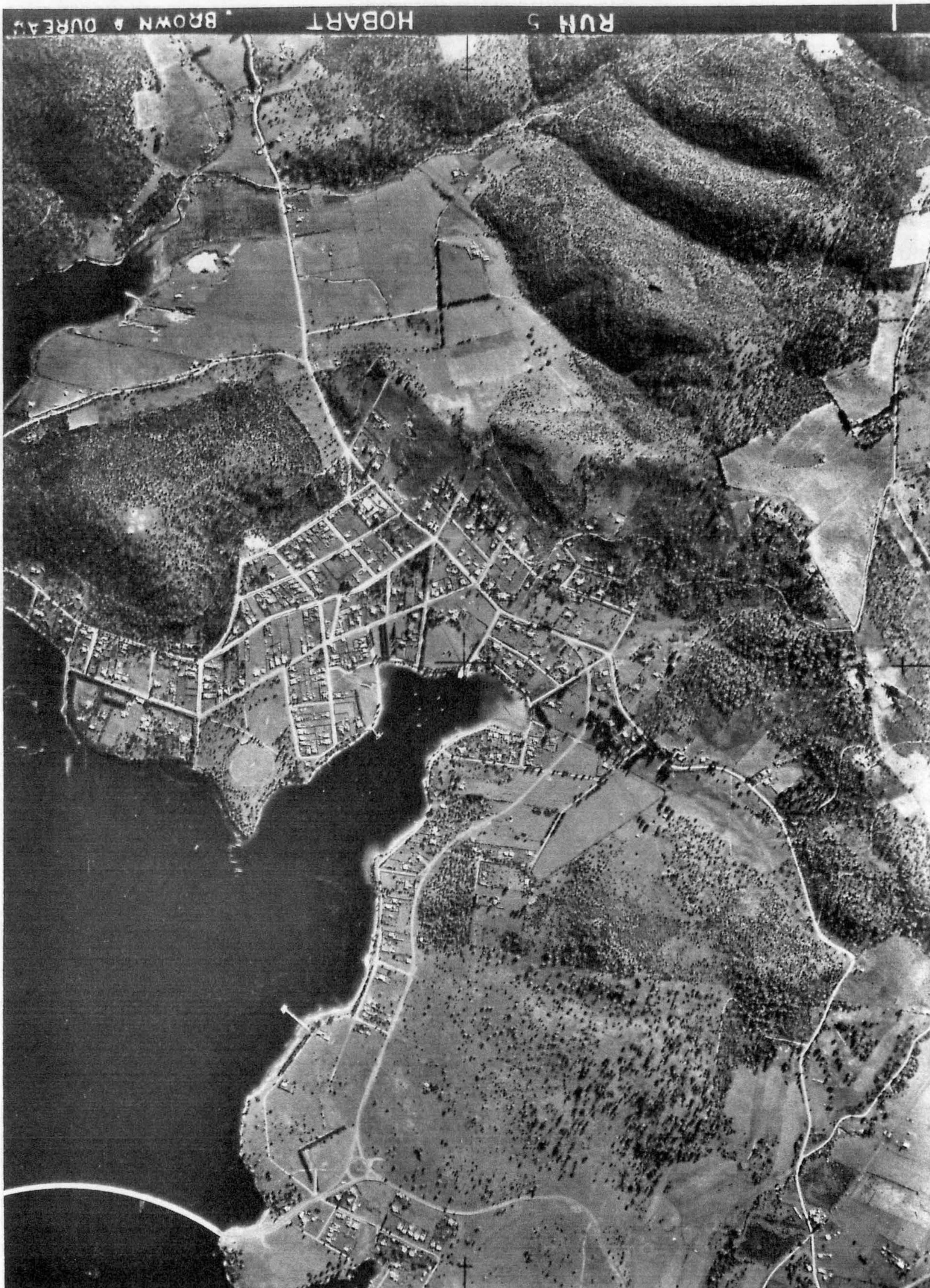

Plate 1.2 Aerial photograph, Lindsisfarne Bay, late 1940s

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Note the exposed foreshore of the northeastern corner of the head of the bay and the relatively undeveloped parts of the catchment

source : Lands Department of Tasmania

Plate 1.3 Aerial photograph, Lindisfarne Bay 1984

Note the reclaimed area in the northeastern corner of the head of the bay and the extensive urbanisation as compared with Plate 1.3

source Lands Department of Tasmania

be adopted to changed needs (Hepper et al. 1985)

The Derwent River Management Plan described Lindisfarne Bay thus:

> ...the northern foreshore and head of Lindisfarne Bay have been extensively modified and reclaimed and there is evidence of siltation and foreshore erosion.
>
> (Hepper, Marriot & Associates 1985)

It listed among enhancement opportunities for Lindisfarne Bay the following:

> (i) monitoring and reduction of siltation of the bay
> (ii) stabilisation of foreshore erosion.
>
> (Hepper, Marriot & Associates 1985)

However it did not present a practical program to achieve these aims.

The sedimentation in Lindisfarne Bay has been of considerable concern to the local community. As a result, a local action group known as the Lindisfarne Bay Beautification Committee was formed in 1985. This committee still meets regularly and aims to enhance the beauty of the Bay by whatever means are appropriate. It acts as a pressure group and suggests tasks to the local municipal authority, the Clarence Council. Three members of the committee are also members of the Clarence Council. Therefore the committee has considerable impact on decisions made by Council.

It was successful in obtaining funds from the Council to commission consultants to develop an appropriate management plan for Lindisfarne and Geilston Bays (Lewis & Duvivier 1988) so that the two bays could be rehabilitated. Council, at the time of writing were considering the consultants' report (Southern Star June 26, 1988).

1.3 Aims of the study

The aims of this study were:

(a) to determine the rate of change of sedimentation in the Lindisfarne Bay area by use of a radiotracer technique;

(b) to determine whether heavy metals were present in the sediments;

(c) to suggest possible sources of the sediments; and

(d) to relate the land use history of the bay area to sedimentation and any heavy metal pollution.

Two main approaches have been adopted. Firstly a record of historical changes to the bay, complemented by archival research and oral history interviews, has been established. Secondly sediments have been examined physically. Eight core samples were taken in the intertidal zone at the head of the bay for caesium-137 (^{137}Cs) dating. Associated with dating of the sediment cores, a physical examination of factors likely to link them with land use activities was undertaken. Thus, grainsize analysis and determination of concentrations of four of the major heavy metals from the nearby Electrolytic Zinc Works (EZ) has been carried out. Grainsize analyses assisted in an understanding of the local water dynamics and the source of sediments within the bay. Heavy metal concentrations were determined so that a correlation of known heavy metal discharges to the river with concentrations in dated sediments could be made.

It was hoped that this study, by its examination of land use history and its determination of rates of change of sedimentation would lead to a better understanding of the sedimentation problem and, in so doing contribute to the management plan enhancement objectives outlined in the Derwent River Management Plan.

1.4 Strategies for unravelling the sedimentation problem

The classical approach to examining sedimentation involves the adoption of a program to sample grainsize, grain shape and mineral components.

Several methods for estimating sediment accumulation rates from aqueous systems are presently in use (Wise 1980, Oldfield 1986). Most are based on measurement of tracer profiles (eg. pollen, uranium/thorium-series nuclides such as lead-210 (^{210}Pb) (Christensen & Scherfig 1978, Skei 1983, Santschi et al. 1984, Paez-Osuna & Mandelli 1985) and radiocarbon (Colhoun & Moon 1984) or the occurrence of anthropogenic chemicals including nuclear bomb fallout nuclides such as ^{137}Cs (McCallan et al. 1980, McHenry & Ritchie 1980, McHenry & McIntyre 1984, Ritchie & McHenry 1984, Campbell et al. 1986a, Miller & Heit 1986, McIntyre et al. 1987, Loughran et al. 1988). Heavy metal accumulation has been studied in association with radioisotope dating (Batley 1987) and is discussed in more detail in Section 4.1.

Radioactive decay provides methods for dating on all geological timescales and derives dates from the rates of radioactive decay associated with particular radioisotopes (Oldfield 1986). Potassium-argon dating, for example, can provide timescales of millions of years. At the other extreme, the radioactive decay of beryllium-7 can help to resolve changes taking place within a single year (Oldfield 1986). However, it is the time scales that lie between these two that have particular application to environmental problems. Interest in determining the recent accumulation rates and the history of anthropogenic activities has fostered widespread use of the ^{210}Pb method (Oldfield & Appleby 1984). ^{210}Pb is a naturally occurring radioisotope resulting from the radioactive decay of the gas radon which is, in turn, a product of the radioactive decay of radium-226 in the earth's crust. It has a half life of 22.26 years and so can often provide dates for the last 100 to 150 years. It is especially suitable for use in lake, marine and estuarine sediments though it has also been applied to peat bogs, salt marshes and snowfields (Oldfield 1986).

Unlike ^{210}Pb, ^{137}Cs is entirely a by-product of atomic bomb testing. Its half life of 30 years also makes it quite suitable for longer term dating, but in practice its application dates from 1954, when it was first detected in signficant quantities (Oldfield 1986). Nevertheless, it has become a useful tool in quantifying soil erosion (Loughran et al. 1986).

Traditionally the Universal Soil Equation has been used as an aid in predicting soil losses from cultivated land (Wischmer & Smith 1965 cited in Ritchie et al. 1974). However, this method of measuring the soil erosion cycle was found to be difficult and usually required several years work, especially in the case of sediment deposition. The loss of soil as calculated by the Universal Soil Equation, was shown to have a logarithmic correlation with ^{137}Cs loss from a watershed (McHenry et al. 1973, Ritchie et al. 1974, Ritchie & McHenry 1975, McHenry & Ritchie 1980). This initial work laid the foundation for the use of ^{137}Cs in determining sedimentation rates in impoundments of flood plains. It was also used as an erosion tracer.

More recently in Australia, ^{137}Cs has been used to obtain direct information on the nett soil loss from a drainage basin at Pokolbin, N.S.W. (Campbell et al. 1982, Loughran & Campbell 1983, Campbell et al. 1986b). The average nett soil loss from this drainage basin was calculated at six tonnes per hectare per year. Similiar work has been carried out on an upland catchment in the Darling Downs (McCallan et al. 1980, Longmore et al. 1983). In both cases mentioned above, without using the ^{137}Cs technique there was little chance of estimating the annual average long-term soil loss notwithstanding repeated and costly surveys of these sites over the equivalent of at least a 30 year period (Loughran et al. 1987).

To best understand this technique one must firstly examine the spread of the radioactive material and its subsequent routing through an ecosystem. The routing of ^{137}Cs from catchment slopes to the stream system is complex (Wise 1980). However, a simple qualitative ^{137}Cs drainage basin model has been created which represents the possible pathways of ^{137}Cs within a catchment system (Campbell et al. 1982) (Fig 1.4). This model has been tested (Campbell et al. 1986b).

Caesium-137, being an artificially generated isotope, is only produced in significant quantities by fission reaction. Thermonuclear explosions have pushed radioactive debris into the stratosphere and winds have spread the material globally. However, the distribution has not been uniform. It has been shown that there are greater levels in the mid latitudes of the northern hemisphere and that levels of ^{137}Cs vary with time (Davis 1963).

Since nuclear weapons testing programs commenced in earnest around 1954, marked variations in radioactive fallout have been noticeable. Such variations, it has been suggested, are due to factors such as:

a testing moratorium (November 1958 - September 1961);

acceleration in atmospheric nuclear tests (September 1961 - August 1963);

a test ban treaty (August 1963); and more recently

French tests in the Pacific Ocean (McCallan et al. 1980).

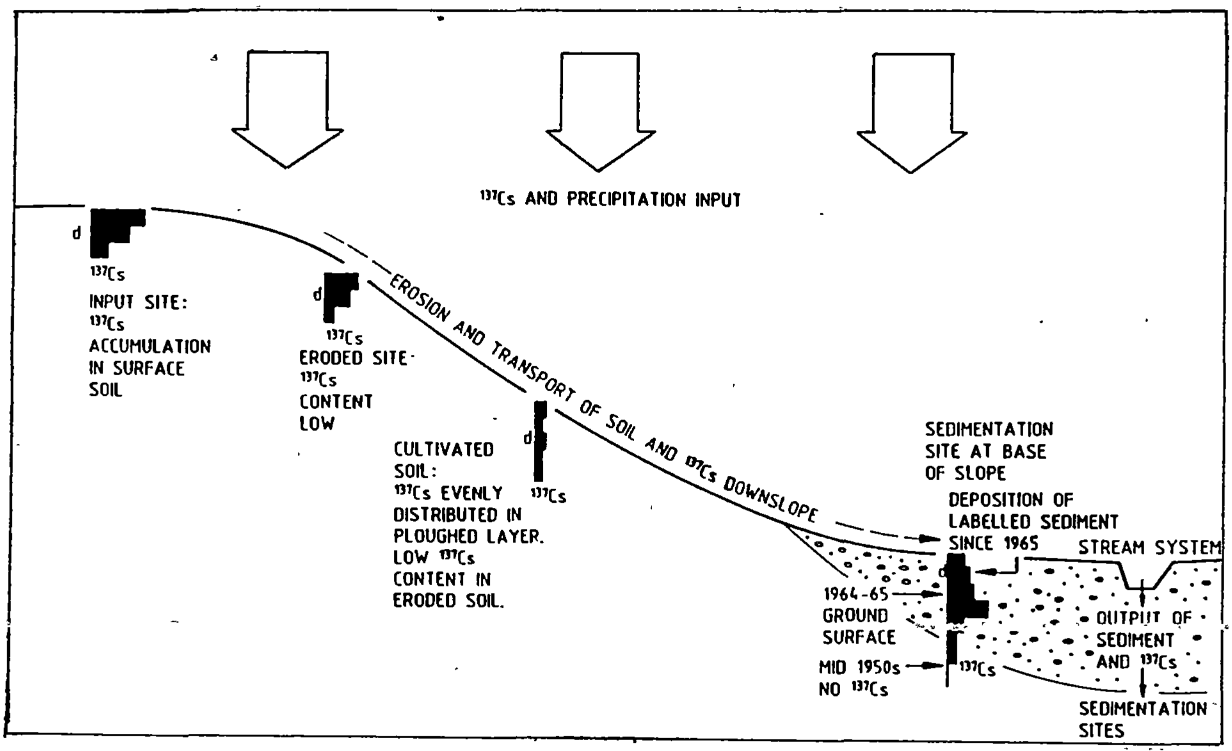


Fig. 1.4 Caesium -137 pathways

This model of ^{137}Cs redistribution on drainage basin sediments reflects the successive atmospheric inputs and the redistribution of soil material by erosion and sedimentation. Campbell et al. (1982), when constructing the model took the following assumptions into account:

(a) fallout of ^{137}Cs from atmospheric nuclear weapon testing is the major source of the isotope;

(b) ^{137}Cs becomes strongly adsorbed to fine soil and remains fixed;

(c) ^{137}Cs is transported with soil during the process of erosion; and

(d) after ^{137}Cs is transported, it is deposited and becomes labelled material on flood plains, alluvial fans and slopes, in reservoirs, in lakes, and in estuaries, forming characteristic concentration profiles

source : Campbell et al. 1982 duplicated from Loughran et al. 1988

A more recent source of radioactive fallout was the Chernobyl disaster in the northern hemisphere, however its impact in Australia with respect to fallout levels is unlikely to be significant (Loughran et al. 1987).

After circulating through the stratosphere, fallout material containing ^{137}Cs may eventually be brought to the earth's surface by rain. The amount of ^{137}Cs deposited in any area will thus be dependent on its atmospheric concentration and the mean annual rainfall in that area. It has been suggested, in fact, that the ^{137}Cs input into a system can be estimated from the mean annual rainfall (Wise 1984).

The majority of ^{137}Cs falling to earth finds its way onto the soil surface. Here it has been shown to be adsorbed by particles of clay, the adsorption mechanisms being ion exchange with the clay minerals (Tamura 1964). Clay deficient and organically rich soils have been shown not to adsorb ^{137}Cs readily (Miller & Heit 1986). As well, the adsorption of ^{137}Cs by vegetation and plant roots has been shown to be negligible (Davis 1963) . The routing of ^{137}Cs through a catchment thus results in accumulation, largely in the top 300 mm of the soil profile (McHenry et al. 1973). Once the ^{137}Cs has been adsorbed by the surface soil it has been shown to be virtually non-exchangeable which results in an exponential decrease in concentration with increasing depth below the surface of undisturbed soils (Wise 1984). It is this property, of being non exchangeable once being adsorbed by clays, that has enabled it to be used as soil erosion tracer.

The radioactive tracer technique has not been widely used on highly mobile riverine estuarine sediments. One study, carried out using ^{137}Cs as well as the plutonium isotopes (^{238}Pu, ^{239}Pu & ^{240}Pu) in tidal marsh sediments showed a highly variable depth deposition (Hayes & Sackett 1987). They suggest that desorption of ^{137}Cs maybe occurring as result of particles encountering the saline water of the sea.

In this study of the Derwent Estuary, ^{137}Cs dating has been preferred to ^{210}Pb dating. The major factor determining this choice was the ready availability of the necessary detection equipment from the Australian Nuclear Science and Technology Organisation. Secondly, financial constraints were also taken into account.

1.5 Contents of the study

As outlined earlier, two different approaches have been adopted in examining the sedimentation problem. The following chapters have thus been structured to accord with these two strategies.

Chapter 2 discusses the land use history of Lindisfarne Bay. Firstly, the relatively pristine state of the bay prior to colonisation, and the effect of European settlement in and around Lindisfarne, are considered. Population growth has been viewed in the context of increasing land development. Further developments understood to have influenced the magnitude and rate of sedimentation, such as land clearance for housing, changes to the river catchment, fire regime, sewage, and landfill have been discussed. Finally, heavy industries proximal to the bay and likely to be a major source of heavy metal pollution have been described.

Chapter 3 examines the physical environment of the bay and its surrounding catchment area. Some emphasis has been placed on hydrological conditions in the bay. Other physical environmental factors discussed include climatic conditions, geology, vegetation, soils, flora and fauna, and water quality. These have been considered in terms of their influence on sediment dynamics.

In Chapter 4, a study of the sediments themselves is reported. Dating of sediment deposition, using the ^{137}Cs nuclide technque was carried out by a purpose-built coring device. The corer has been fully described in Appendix B. Methods, results and discussion for each of the three sampling parametres (^{137}Cs, heavy metals and grainsize analysis) precedes a synthesis of the results. A section covering possible pesticide residues in the sediments is also included.

The fifth and final chapter presents a summary and future management options. The use of ^{137}Cs in determining sedimentation rates and the compatibility of heavy metal deposition as a secondary time indicator are discussed. Finally, suggestions are made as to the management of the Lindisfarne Bay area.

1.6 Limitations in scope

Although an environmental examination of the sedimentation problem in Lindisfarne Bay, the study is purely concerned with the aims listed in Section 1.4. Despite its title it does not embrace all the factors inherent in the term 'environmental' (O'Riordan 1981). For instance the study does not cover the philosophical, political or economic aspects of the problem. The study does have limitations which include:

(a) the data base of circulation dynamics of the bay, and estuary more generally is poor; no attempt was made to carry out current measurements as it was considered a project in itself and well beyond the scope of the study;

(b) the use of the ^{137}Cs technique has not previously been carried out in Tasmania and levels of input activity of ^{137}Cs for the region were unknown prior to this work;

(c) the use of the ^{137}Cs technique in a dynamic system such as an estuarine bay has inherent complications with respect to interpretation of results;

(d) no attempt was made to identify the source of the sediments; grainsize only, not grain shape or mineral components, was examined;

(e) no attempt was made to examine criteria which were visually apparent in Lindisfarne Bay, such as eutrophication or nitrification; and

(f) although suggestions bave been made as to possible management options based on results obtained, rehabilitation measures are not addressed.

CHAPTER 2

LAND USE HISTORY

2.1 The pristine state of Lindisfarne Bay prior to European settlement

There is abundant evidence to suggest that a substantial population of Aborigines was living on both sides of the Derwent Estuary about 5800 years ago (Sigleo & Colhoun 1975, Healey & Stockton 1980) and that vegetation burning was extensively practised by the Aborigines in the area. The amount of colloidal humate and charcoal in estuarine sediments, found during examinations of core samples taken during construction of the Bowen Bridge at Dowsing Point in 1977 (Colhoun & Moon 1984), reinforces this evidence and indicates that the Aborigines had a significant cultural impact on the land surface during that time. Colhoun & Moon (1984) go as far as to say that their impact 'caused much soil erosion and contributed substantial sedimentary loads to the rivers that entered the estuary.' The Aboriginal practice of firing the land may, in fact, explain why dry sclerophyll Eucalyptus forests flanked the estuary at the time of European settlement (Colhoun & Moon 1984). They further added that

> the fossilised leaves of Nothofagus cunninghamii occur in such abundance and in such good condition that they require a local source, which suggests that temperate rainforest or mixed forest occurred in the area during the early Holocene.
>
> (Colhoun & Moon 1984)

Written and photographic archival material from the State Library has been examined and interviews with long term residents (Appendix A) of the relevant area carried out in order to attempt to establish the condition of the Lindisfarne Bay foreshores prior to European settlement.

Emphasis has been given to the probable existence of sandy beaches in the head of Lindisfarne Bay, since beaches derived from marine sediments are generally a feature of salt water type estuaries. Some marine deposits throughout Tasmania have been shown to be of Last Interglacial age (van de Geer et al. 1979) and the oldest formation of sandy silts and clays in the Derwent Estuary have also been suggested to be of this age (Colhoun & Moon 1984). Upstream movement of marine sedimentary material was observed long ago, and in a conclusive study of the Atlantic Coastal Plain, (Meade 1969, cited in Forstner & Wittmann 1981) it was demonstrated that sediments had progressively moved landward along the bottom. The key factors in these transport processes were river water inflow, the river sediment discharge, and the force of tidal currents.

Evidence cited below indicates that Lindisfarne Bay exhibited a very different coastline prior to European settlement than it does today. Both the northwestern and northeastern corners of the bay

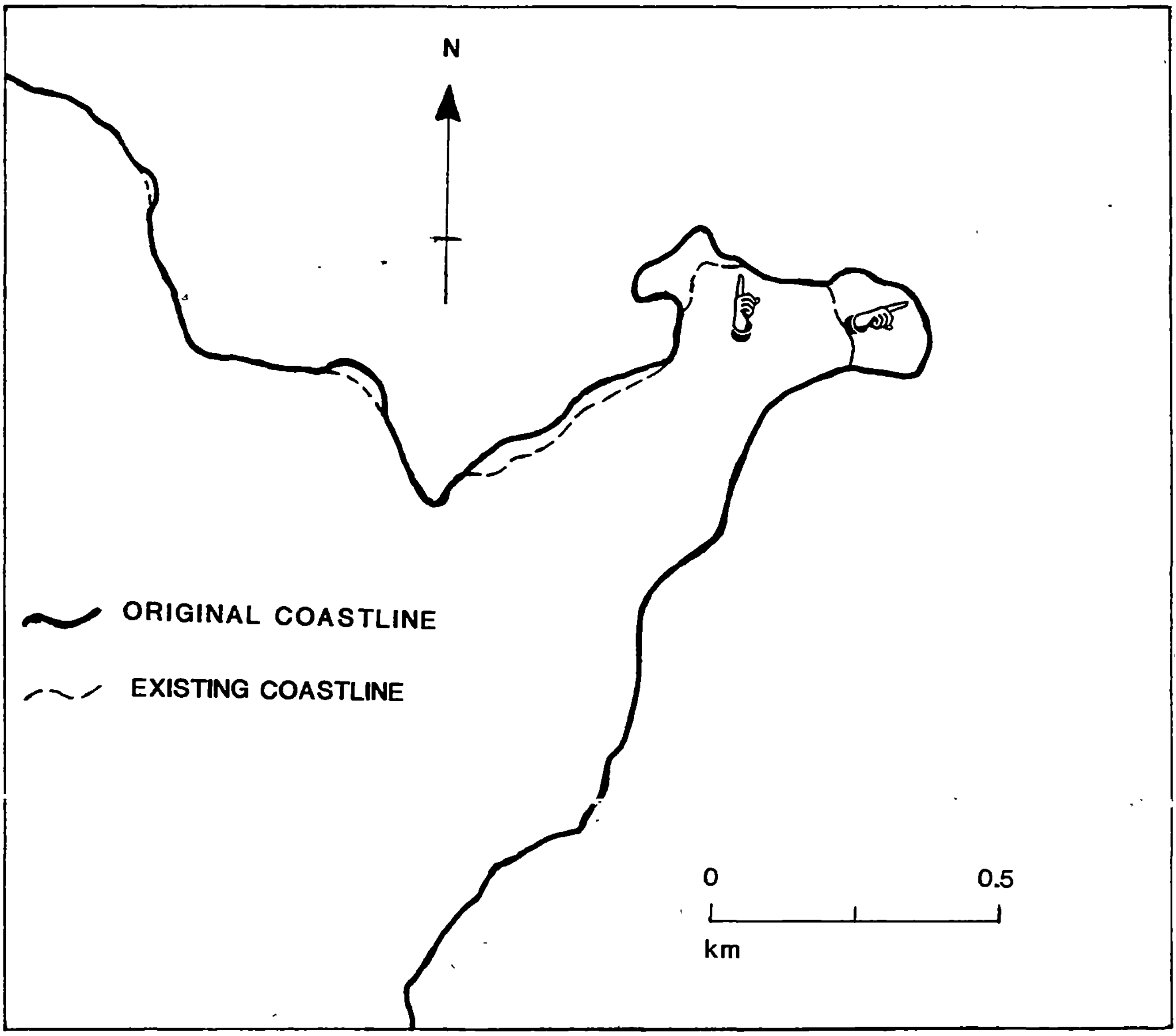


Fig. 2.1 Coastline of Lindisfarne Bay, circa 1800

Beaches have been identified by historical record at two sites in the head of the bay and are shown by finger points; the dotted line, representing the present coastline, shows that substantial reclamation has taken place ; the beaches have become degraded due to sedimentation

source : compiled by historical records 1985

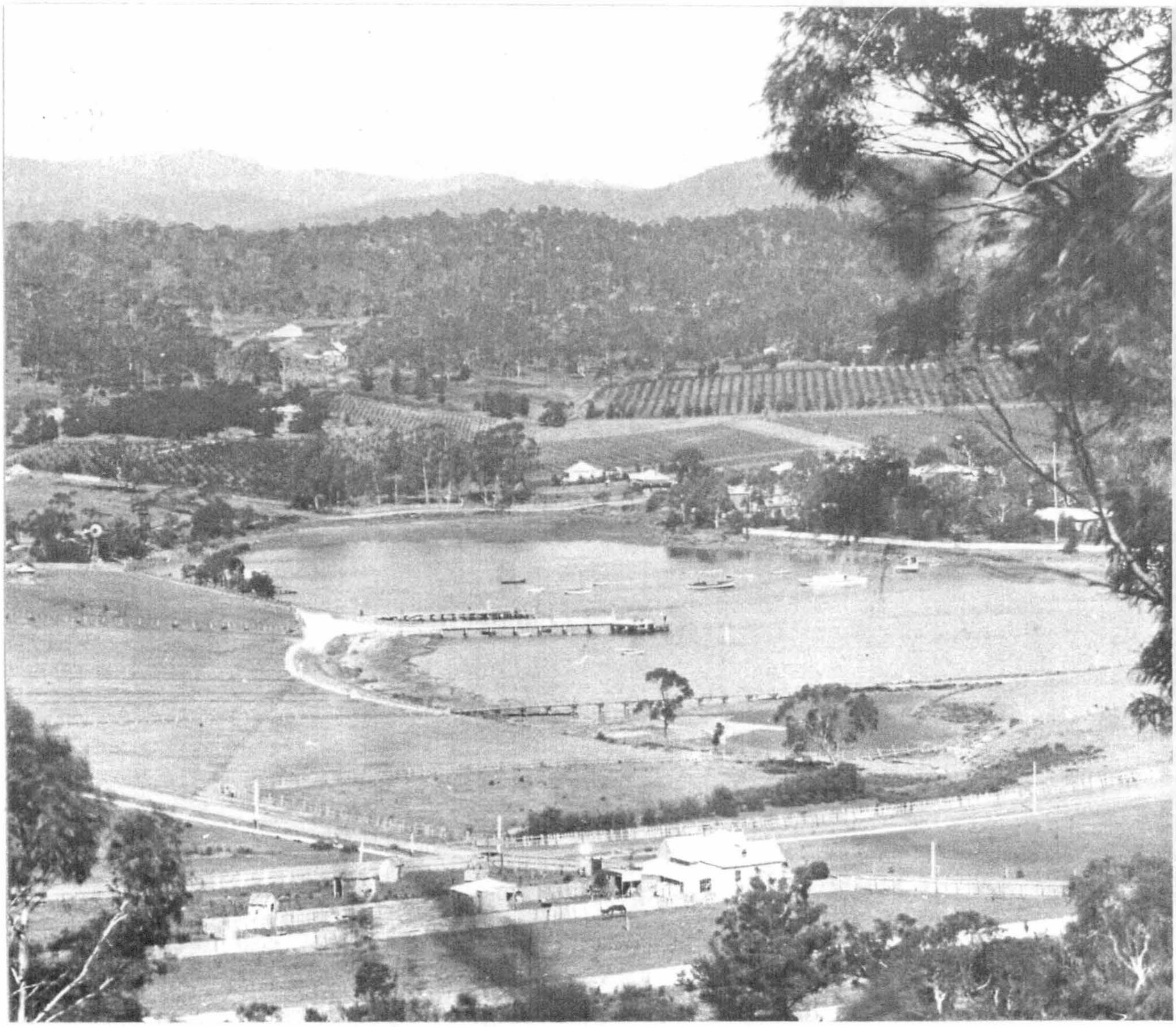


Plate 2.1 Lindisfarne Bay from Natone Hill, 1910

Agricultural development and the rural character of the landscape were features of the area during this period

source : Tasmanian State Library Archives appear to have changed substantially (Fig 2.1) (Plate 2.1). Evidence suggests that sandy beaches did exist in the bay and their use by early pioneers has been implied (Evans 1967). Beaches have also been identified at two locations in Lindisfarne Bay (Wood 1985). One beach site described as 'being of golden sand' was located at the head of the bay on the north shore (Fig 2.1) Ford (pers. comm.) and Gibson (pers. comm.). Apparently, sand extended into the northeastern corner of the bay and the shoreline consisted of a gentle slope. The above is supported by the identification of sand and shells overlain with silt and mud from samples obtained for grainsize analysis at approximately a two m depth. It should also be noted that this area has since been reclaimed by landfill.

Another small beach was apparently present on the northwestern side of the bay (Fig 2.1) (Ford pers. comm., Gibson pers. comm.). Sand occurs at this site today thus supporting the existence of a beach.

The catchment of Lindisfarne Bay, which contained dry sclerophyll Eucalyptus forest typical of present day southeastern Tasmania, is discussed in detail in Section 3.4.

2.2 History of European settlement 1797 - 1946

The first Europeans to visit Lindisfarne Bay were Bass and Flinders in 1797 (Evans 1967). In 1828, Thomas George Gregson selected a grant of 7000 acres of land stretching from Risdon to Kangaroo Bay (Fig.1.2). Gregson had social status and the pecuniary means necessary to procure such land which he named Lindisfarne to reflect his Anglo-Saxon memories of Old England (Mercury June 18, 1898). Records indicate that it was once known as Oglemans Bay. However, the name Lindisfarne can be traced back to the early 1800s (Davonport pers. comm.).
The area around Lindisfarne remained undisturbed for many years and when approached from the western shores of Hobart appeared as 'a succession of inland promontories clothed with undisturbed vegetation thus causing it to be christened Beauty Bay' (Mercury June 18, 1898). Lindisfarne also came into some prominence when a poem reflecting it's beauty was published in 1825 (Hobart Town Gazette June 17, 1825).

In 1839, Lindisfarne's first resident was John Price who came from the convict settlement at Huon in southern Tasmania. Price obtained an 80 acre lease from Gregson and procured from the Government a reliable supply of convict labour to clear and till his leasehold (Davonport 1988). He was known for his strict supervision over the convicts and also for an energetic approach to pioneering. Some idea of Price's unbending nature can be gleaned from an article which appeared some fifty years later and covered life in the colony in Price's time (The Critic 1889 cited in Davonport 1988).

In this article mention was made that:

> At one time, the pretty little bay of Lindisfarne and its foreshores was a sealed enclosure; public rights were impossible. The place could only be viewed at a distance anyone caught there was severely dealt with by John Price
>
> (The Critic 1889 cited in Davonport 1988)

Nevertheless, Price was regarded with respect in some quarters and was described as a stern and just man and one of Van Diemen Land's most courageous pioneers. Extensive clearing of the land occurred and timber from trees cleared from within the catchment was used to construct the first jetties. Lindisfarne soon exhibited marked agricultural progress (Plate 2.1). In 1846 Price departed and was eventually murdered at Williamstown in 1857 (Davonport 1988).

In 1882, the Beltana Town Board (now known as the Clarence Council) listed only two properties at Lindisfarne for its annual rate assessment, namely a farm with a cottage, and land. Both the farm estate and the land were subdivided into allotments suitable for building purposes in 1890, when a syndicate was formed to develop the area. Two reserves, one of 25 acres and the other of about two acres, were acquired by the Board.

In 1892, at the suggestion of a prominent citizen, a Mr. Simmonds, the name Beltana was bestowed on the town. This was an Aboriginal word meaning running water. The area continued to be known as Beltana until 1903 when, again at the suggestion of Mr. Simmonds, it reverted back to the name Lindisfarne (Davonport 1988).

In 1890 an Arbor Day ceremony was arranged in Beltana. As part of the ceremony, the first trees were planted in the district. Regrettably, by 1923 all of the trees planted at that time had disappeared (Davonport 1988).

Some of the prophecies of the print media at the turn of the century about Beltana included 'Beltana is undoudtledy becoming the Ramsgate of Hobart' (Tasmanian Mail 1892 cited in Davonport 1988) and 'Lindisfarne is destined to become a popular holiday sanatorium' (Mercury June 18,1898).

The O'May family also played an important part in the settlement of Lindisfarne, particularly in the field of transport. They were pioneers of the trans-Derwent ferry services which began around 1892 to develop settlement in the suburbs and provide communication with Hobart. A very reliable service was provided by the O'May's for over forty years.

Meanwhile in Hobart Town, the 1850's had been a period of prosperity marked by unbounded optimism in the future of the city. However adverse economic conditions which were to last about 20 years led to the gradual decline of Hobart as the second city of the Australian colonies. The population of Hobart remained static at less than 20,000 from the 1850's to the 1870's. Relatively prosperous times returned in the 1880's with the introduction of services such as the telephone and electric street lighting. In 1876, the tragic story of white settlers' inhumanity and indifference to the island's original inhabitants came to a climax with the death of Truganinni, believed to have been the last full blooded Tasmanian Aborigine. By 1901 Hobart had a reasonably static population of 24,654.

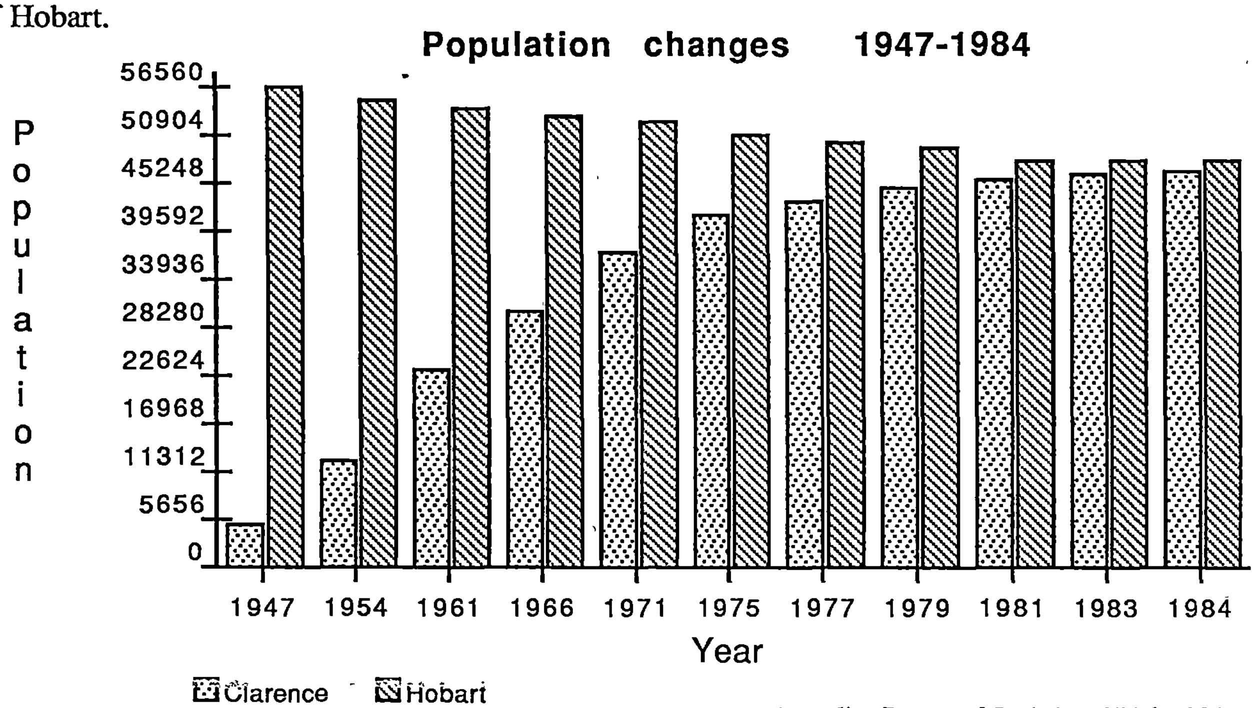
Lindisfarne experienced substantial building activity between 1901 and 1910 as evidenced by early landscape photographs of that period (Plate 2.1). In 1905, an aquatic carnival was held in Lindisfarne Bay and the Lindisfarne Bay Rowing Club held a grand concert and operatic performance. In 1913, a Clarence Councillor remarked when on a tour of Lindisfarne that the thriving apricot orchards were a prominent feature of the landscape (Tasmanian Mail November 2, 1913). The first school was built in 1914. Population remained steady between the First World War and the Second World War.

From 1943, the Clarence Municipality experienced spectacular population growth (Robinson et al. 1972) following the opening of a floating bridge in December of that year (Plate 1.2). It extended from the Botanical Gardens on the west side of the river to the head of Montagu Bay on the east side (Fig 1.2). This bridge was closed to traffic in 1964 following the completion of the Tasman Bridge. The floating bridge was dismantled and sections were sunk at various locations along the river and along Tasmania's east coast.

On January 5 1975 an ore-carrying ship, the Lake Illawarra crashed into one of the supporting pillars of the Tasman Bridge across the Derwent while en route to the zinc refinery located upstream. The bridge was cut in two and the ship sank, taking with it thousands of tonnes of heavy metal containing ore. The river is deep at this point, and the vessel and its cargo were not salvaged. 'The zinc sulphide ore has not been considered a serious source of pollution' (Beckmann 1987). The ship is now covered with a blanket of silt, and heavy metals within the cargo are effectively buried however the possibility of leaching of heavy metals from the vessel cannot be dismissed without further detailed monitoring.

2.3 Changes in population and housing 1947-1986

The Clarence municipality has changed from a small rural region of less than 4000 people in 1943 to a rapidly expanding urban area with a population approaching 40,000 in 1972. It was one of the fastest growing municipalities in Tasmania. The population increase led to the conversion of rural land to urban land by subdivision, decreasing land availability for farming, and increasing alternative usage of the bays and beaches particularly for recreational activities (Robinson et al.1972). Fig 2.2 shows population changes of the Clarence Municipality compared with the City of Hobart.



source: Australian Bureau of Statistics 1976 & 1986b

Fig. 2.2 City of Hobart & Clarence Municipality Populations 1947-1984

Figures published by the Australian Bureau of Statistics (1976 & 1986b) show that the period 1947 to 1954 was one of high population growth rates for Tasmania, this growth being mainly due to migration and the effect of the post war 'baby boom'. Again, for the intercensal period 1954 to 1961 there was a rapid increase in the population of the Clarence area, whilst at the time the growth rate of Tasmania as a whole was lower. The period 1961 to 1981 saw a decrease in growth rates for Tasmania as a whole. However, the Clarence area continued to have growth rates above average for municipalities in Tasmania. The annual average rate of change in population for Lindisfarne was +3.2% for the 1981 to 1984 period compared with -9.6% for Hobart and +0.2% for the whole of the state of Tasmania.

2.4 Significant colonisation developments

Whilst the general history of development in the Lindisfarne Bay area is interesting, of more importance to the work here is the effect that such development might have had on the physical state of the whole Derwent Estuary and particularly on Lindisfarne Bay itself.

Associated with population growth on the shores of the Derwent Estuary went land development, land filling, cultivation and the development of both light and heavy industry. Whilst the river system at its upper reaches gave a ready supply of water for human, agricultural, and industrial use it also provided a ready sink or drain for the dumping of effluents such as sewage and industrial wastes at its lower reaches.

Thus, on top of the natural attrition of the land due to agriculture providing an increased load of soil and clay type sediments in the estuary, there have been the addition polluted sediments from human and industrial wastes. Finally, the Derwent River was dammed at various points along its length, thus providing for the generation of hydro-electricity to satisfy the increasing demands of a growing population with expanding industry.

All of these factors, which will be discussed in greater detail in the sections to follow, must obviously have had an effect on the whole of the Derwent Estuary, including Lindisfarne Bay.

2.4.1 The Electrolytic Zinc Works

Zinc is mined as the mineral sphalerite in western Tasmania as well as at other locations in Australia. It is shipped as a zinc concentrate to Hobart, where it is treated for recovery of the pure metal by an electrolytic process (Electrolytic Zinc Company of Australasia Limited, undated).

The Electrolytic Zinc Company of Australasia Limited (EZ) operates its Risdon works on the west bank of the Derwent Estuary. It is thus accessible by sea transport and within easy reach of all parts of greater Hobart (Fig. 1.2). The company was formed in 1916 to test and develop the then new electrolytic refining processes on Broken Hill concentrates. In 1917, a miniature zinc plant was established on a laboratory scale, producing 114 kg of zinc per day. This was followed in 1918 by a semi-commercial plant producing some 10 tonnes per day. Production was gradually increased to 100 tonnes per day in 1922 after the process was proved to be viable. As well, EZ played an important part in the development of Tasmania's hydro-electric system. As a result of the large amounts of electricity used in the electrolytic refining proceses, the EZ company became one of the first companies to obtain concessional rates for bulk power use from the Tasmanian Hydro Electric Commission. Thus the plant has historical significance linking it with hydroindustrialisation. Although the plant has been maintained and extended since 1922, in many respects it has not kept up with technological advances in the field and remains old fashioned compared with similar plants around the world. It should also be noted that the design of the original plant, as well as some of the later work, took place at a time when contamination of the environment was not considered important (Beckmann 1987).

The EZ plant has in fact been discharging metallurgical liquid effluents into the Derwent Estuary since it first began production. The relatively small initial inputs to the river of arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), zinc (Zn), and other metals had by 1977 been increased many times over as zinc production increased (Bloom & Ayling 1977). At the same time, solid wastes were either dumped at sea off the Tasmanian coast or piled at Inshallah, a dump on the banks of the Derwent which started in 1941.

It is also well known that, in the period 1957 to 1974, the Derwent Estuary was recognised as one of Australia's most polluted estuaries and was considered to be 'most severely affected by mining and metallurgical waste' (Senate Select Committee 1970, Director of Environmental Control 1972, both cited in Bloom 1975).

In 1974, recovery of metals from plant residues was increased dramatically due to improvements in processing techniques and methods. At the same time, limestone supplanted calcine as the neutralising agent during iron purification, thus reducing the heavy metal content of the iron precipitate made by this process (Hamdolf pers. comm. 1988). Prior to October 1974 this precipitate had been disposed of in the estuary. Since that date it has been disposed of by including it with jarosite dumping at sea. EZ suggested that as a result of these changes there has been an 80% drop in total levels of all metals from effluents in the Derwent (Hamdorf pers. comm. 1988).

Prior to 1974, oyster leases had been established in Ralphs Bay, a shallow bay off the main channel of the Derwent estuary, 15 km downstream from Risdon and with a mean depth of only 3m (Fig. 1.1). Severe cases of nausea and vomiting amongst consumers of oysters from these leases led to an investigation of the metal content in oysters from the Derwent Estuary as well as from other areas around the state of Tasmania (Thrower & Eustace 1972, 1973, Ratkowsky et al. 1974, Eustace 1974, all cited in Cooper et al. 1982). Oysters were found which contained zinc at concentrations of 10,000 ppm or μg/g on a dry weight basis. High levels of Cd (35ppm), Cu (148ppm) and Pb (17ppm) were also detected. Subsequently the oyster leases were abandoned and legal action taken by the lessees against EZ, which was settled out of court (Beckmann 1987).

The most comprehensive investigation of heavy metal pollution in the Derwent River so far is that of Bloom & Ayling (1977). They carried out analysis to determine the concentrations of the metals cadmium (Cd), cromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni) and zinc (Zn) in filtered waters, suspended particulates, sediments, shellfish, fish, airborne particulates and sewage. Their work confirmed the work of other investigators (Department of the Environment Tasmania 1973, 1974, 1975, 1976, [Colbeck & Holdsworth undated, Lytton 1977, Hughes 1975, all cited in Cooper et al. 1982]) showing that the Derwent Estuary was, at the time the analyses were carried out, heavily contaminated, particularly with Hg, Cd, Pb and Zn.

As a result of these studies on metallurgical pollution of the estuary, EZ undertook a program of environmental controls aimed at preventing further pollution of the Derwent River. As well as a change in roasting technology and the discontinuance of iron precipitate discharge to the estuary, the program included continued operation of the Residue Treatment Plant (RTP) first commissioned in 1971 and the establishment of a Contaminated Waste Water System in 1981 (Hamdorf pers. comm. 1988).

The RTP had as its raw material primary residues from the processing plant plus material from the Inshallah dump, which was made up of so called waste residues for disposal at sea. The latter material contained about 20% zinc by weight and was accumulating in a large pile near the bank of the Derwent River resulting in fears that some of the zinc laden dust could be blown into the river (Beckmann 1987). The compound jarosite ($K_2Fe_6[SO_4]_4[OH]_{12}$), the main component of the dumped material, inevitably contained Zn, Pb, Cu and Cd and other heavy metals as contaminants. It is still dumped at sea under a Commonwealth Government Licence and EZ is thought to be the only zinc works in the world still disposing of jarosite at sea (Skei pers. comm.). This situation exists because a suitably stable land fill site has been difficult to locate (Bloom pers. comm.).

The Contaminated Waste Water System is a waste water recycling plant consisting of settling ponds that collect rainwater run-off and other liquids which drain from the zinc plant. It performs a solid/liquid separation and returns the liquids to the main plant. The solids are also returned when the ponds are drained.

Other improved house keeping practices stated to have been introduced by EZ (Hamdorf pers. comm. 1988) include:

(a) new foreshore conveyor system for delivering concentrate from the wharf to the roaster with new gantry cranes erected on the wharf during 1983/84;

(b) concentrate from the new Elura Mine was treated for the first time in 1983. As a result, an iron purification section was commissioned in order to handle the higher arsenic levels which the Elura concentrates contained. These improvements, according to EZ, reduced losses from the plant to fifty percent of the 1973 levels.

Production of zinc at the EZ plant is currently up to 600 tonnes per day amounting to more than 200,000 tonnes of zinc per year. However, with improvements in production techniques, improved housekeeping and stricter environmental controls, EZ now claim that 96 percent of metals, which prior to the early 1970s were finding their way into the river, are now being recovered (Electrolytic Zinc Company of Australasia Limited, undated pamphlet). Despite this alledged inproyement, EZ still holds a Ministerial exemption under the Environment Protection Act 1973 for emitting heavy metals in liquid effluent in excess of the Environment Protection (Water Pollution) Regulations 1974. Ministerial exemptions were granted so as to allow a lead time for existing industries to come into compliance with the Act. It is unfortunate that today, due to lack of political will, poor staffing levels in the Department of Environment and lack of environmental conscience by industry that Ministerial exemptions remain. With proposed upgrading and expansion of the plant, EZ is committed to a program which will apparently lead to substantial compliance of the relevant standards within four years.

The Ministerial exemptions levels granted to EZ are well above those specified in the standards. Levels currently discharged by EZ into the estuary were unavailable however it has been asserted that the Ministerial exemption levels have been exceeded on occasions (Lynch, Coordinator of Friends of the Derwent, personal communication 1988)

2.4.2 Dams on the Derwent River

As population increased and industrial growth occurred there was a demand for more power, particularly after World War II. Consequently, a number of dams for hydroelectric power production were built along the Derwent River.

The main catchment for the Derwent system has associated with it, large storages at Lake St. Clair commissioned in 1937, Lake King William commissioned in1949, and Lake Echo commissioned in1952, which feed power stations on the Nive River (Fig 2.3). On the lower Derwent there are six dams with associated power stations. These involved a two stage development; the first stage involved the commissioning of the Wayatinah Dam in 1957, the Liapootah Dam in 1960 and the Catagunya in 1962. Following this, a final three part development was undertaken with the commissioning of Meadowbank and Cluny Dams in 1967 and Repulse Dam in 1968 (Hydro Electric Commission 1986).

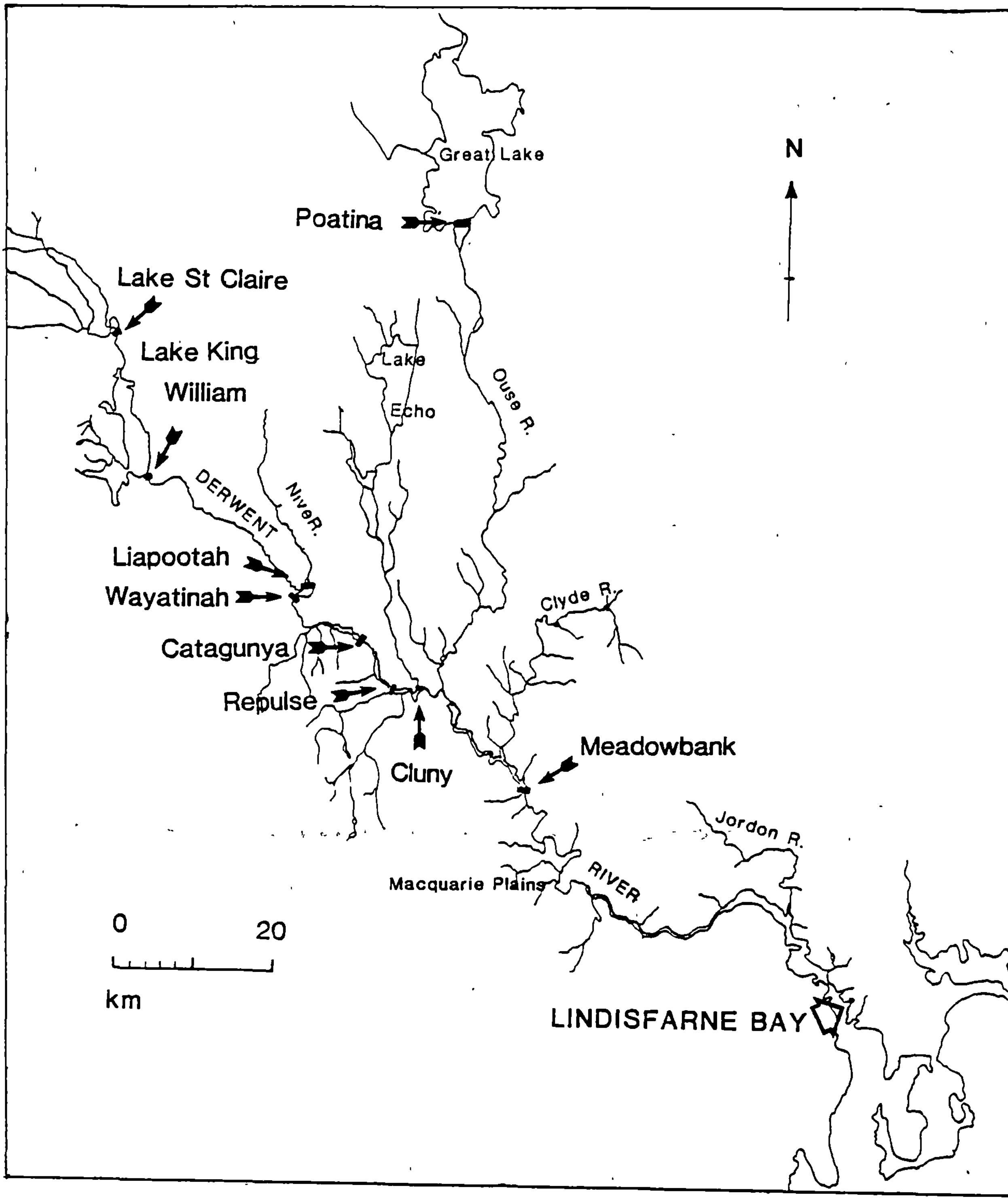


Fig. 2.3 Hydroelectric storages of the Derwent River

Large storages with commissioning dates were Lake St Claire (1937), Lake King William (1949), Lake Echo (1952) and Poatina (1964) which redirected the Great Lake northwards; the lower Derwent storages include Wayatinah (1957), Liapootah (1960), Cluny & Meadowbank (1967), and Repulse (1968); each stage has associated power stations; the overall effect on river flow of these dams has been the control of minimum flows with little effect on floods of a frequency > 2 years due to dam overflow

source : Hydro Electric Commission (1986); map.:1988

The effect of creating highland storages to collect a large proportion of winter run-off, and constructing dams and control gates, has been to reduce the severity of flooding in the Derwent Valley. However, it has had little effect on the estuary itself (Livingstone, Hydro Electric Commission pers. comm.). However the redirecting of flow from Great Lake through Poatina in 1964 instead of southwards to the Ouse River (Fig 2.3), has been suggested as causing the greatest changes in river flow for the Derwent (Livingstone, pers. comm.).

With the building of dams, low flow rates in the river can now be controlled be the release of water from the dam systems, so that flow rates at the low flow level have actually increased after construction of the dams. Thus while prior to 1964 the lowest minimum flow recorded was seven cubic metres per second (cumecs) at Macquarie Plains, the lowest monitoring station on the Derwent River (Fig. 2.3), since that time minimum flows recorded at this same site have not been less than 25 cumecs.

When the river is in flood the dams, once full, overflow and daily flow level variations are noticeable. However overall effects are relatively negligible. Frequency of flooding of periods greater than two years are not affected (Livingstone, pers. comm.).

In summary, the most significant impact of dam construction on water flow in the Derwent River has been the redirection of the Ouse River flow northwards via Great Lake and Poatina. The construction of various other dams on the river and its tributaries appears not to have noticeably altered the flow to the estuary. The overall impact has been the control of extremely low flows with little effect on the frequency of flooding of periods greater than two years.

2.4.3 Fire regime

In the period of quite rapid development of Lindisfarne, the catchment of the Bay appears to have been subjected to indiscriminate land management policies. Firstly, land was cleared for orchards, then in the 1940s as the urban fringe encroached onto the rural bush setting, the Clarence Council undertook regular burning to minimise the risk of fire to person and property. The policy of land management or non-management pursued by the Council during the greater part of this century must obviously have accentuated sedimentation problems in the bay area.

Settlement around Lindisfarne Bay first took place along the coastal fringe and then encroached upon the lower slopes of the surrounding hills. The existing vegetation on the hills of the catchment, especially on Natone Hill, was at that time considered to be a fire hazard. There was no fire brigade so, to reduce the risk of wild fire, the vegetation on Natone Hill was burnt every year from the late 1940's (Cripps, ex-Fire Control Officer, Clarence Council, pers. comm.).

The lower slopes of Gordons Hill were settled later than Natone Hill and were also burnt, but less frequently. In 1967, severe bush fires occurred in and around Hobart leading to the death of many people, and the destruction of many houses and large tracts of bush land. As a result of these bush fires, the following summer a Fire Control Officer was appointed by the Clarence Council. In 1969/70, Natone Hill was completely burnt by the Fire Control Officer which caused an outrage at the time (Cripps pers. comm.). From that time, small areas were periodically control-burnt, usually every three to four years depending upon climatic conditions. Another justification for this fire regime has been the need to stimulate growth of grasses used for grazing on parts of Natone Hill (Cripps pers. comm.).

In 1975/76, Gordons Hill was gazetted as the Gordons Hill State Recreation Area and the Lands Department of Tasmania took over land management control. No controlled burning of the area has apparently occurred since 1975/76. However, there have been deliberately lit fires in the area.

Within the catchment of Lindisfarne Bay, the fragile soils as revealed in Section 3.4, are threatened by erosion following exposure by fire. Once exposed, soils have a much greater tendency to become eroded as was the case when Natone Hill was severely burnt in January 1986, when arson was suspected (Cripps pers. comm.). The writer has observed microterracing on these slopes during 1987.

2.4.4 Landfill

As urban development in the Lindisfarne Bay area increased the quality of water in the bay suffered badly. Foul odours were apparently evident and swimming was soon discouraged. The unsightly and polluted nature of the inner part of the bay is thought to have led to the use of the area as a dump site (Plate 2.2). From 1950 to 1953, 'sporadic tipping of wastes containing no putrescible matter was carried out' (Wardlaw pers. comm. 1985). Control over the tipping was very difficult to police and inevitably putrescible matter was dumped. This led to contamination of the bay by leachate and decaying organic matter.

In 1964, a rock wall was built across the head of the bay. The dumping of rubbish behind this wall continued largely uncontrolled until March 1968. From March 1968 to March 1969 'only tipping by authorised persons was legally permitted' (Wardlaw pers. comm. 1985). The fill material used at this stage consisted mainly of clean building materials, vegetable matter and garden refuse. Eventually the area was completely filled and top soil was brought in and planted with grass seed, thus creating the parkland known today as the Matthew Simmonds Park (Fig. 1.2), (Plate 2.3).

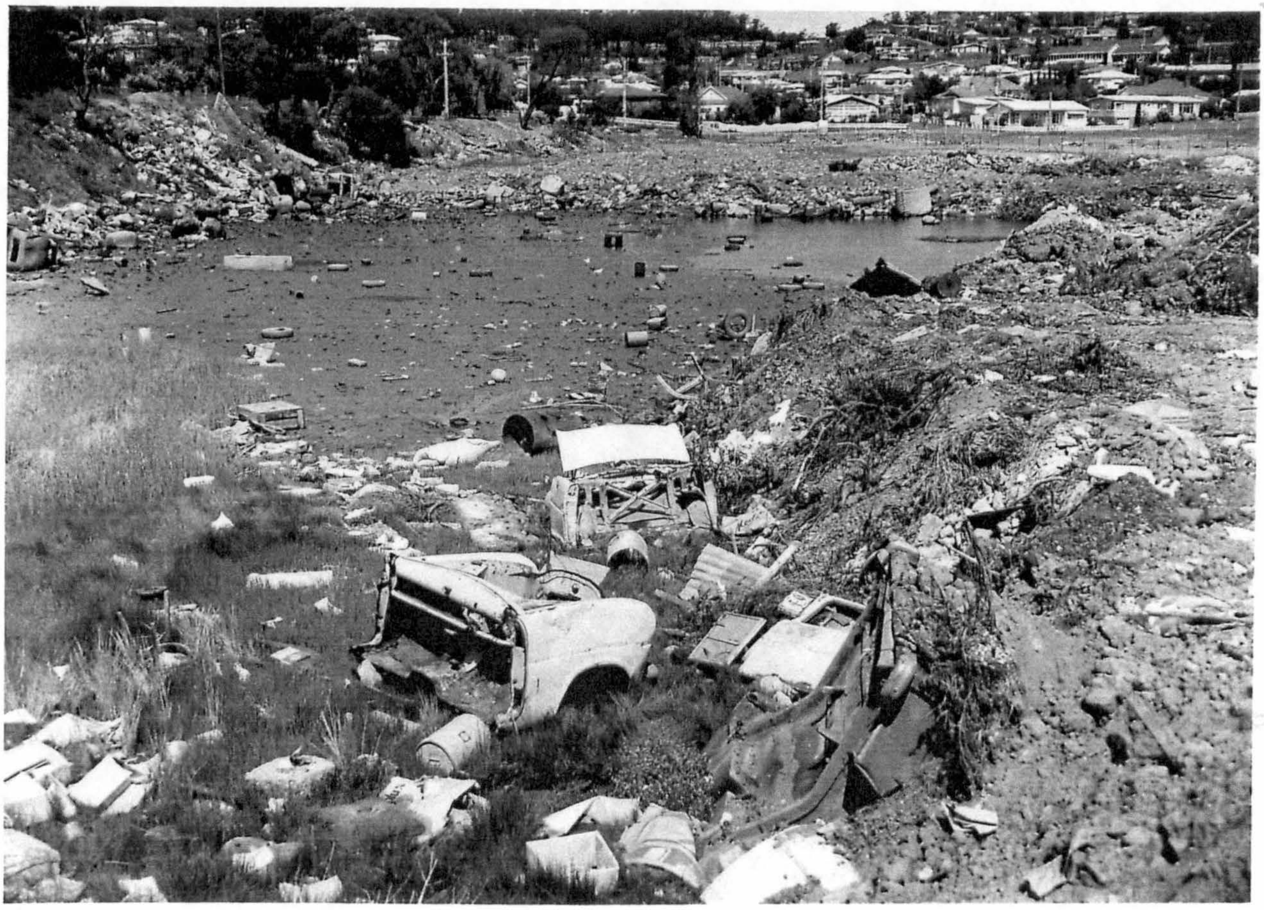


Plate 2.2 Head of Lindisfarne Bay used as refuse site 1939

The northeastern head of Lindisfarne Bay was used as a dump site reflecting the attitude people had to the degrading environment at the head of the bay; subsequent to further sporadic tipping of wastes in the early 1950s, controlled tipping occurred after the erection of a rock wall in 1964 to contain the waste; the area eventually was reclaimed as parkland shown in Plate 2.3

source : Mercury archives Hobart

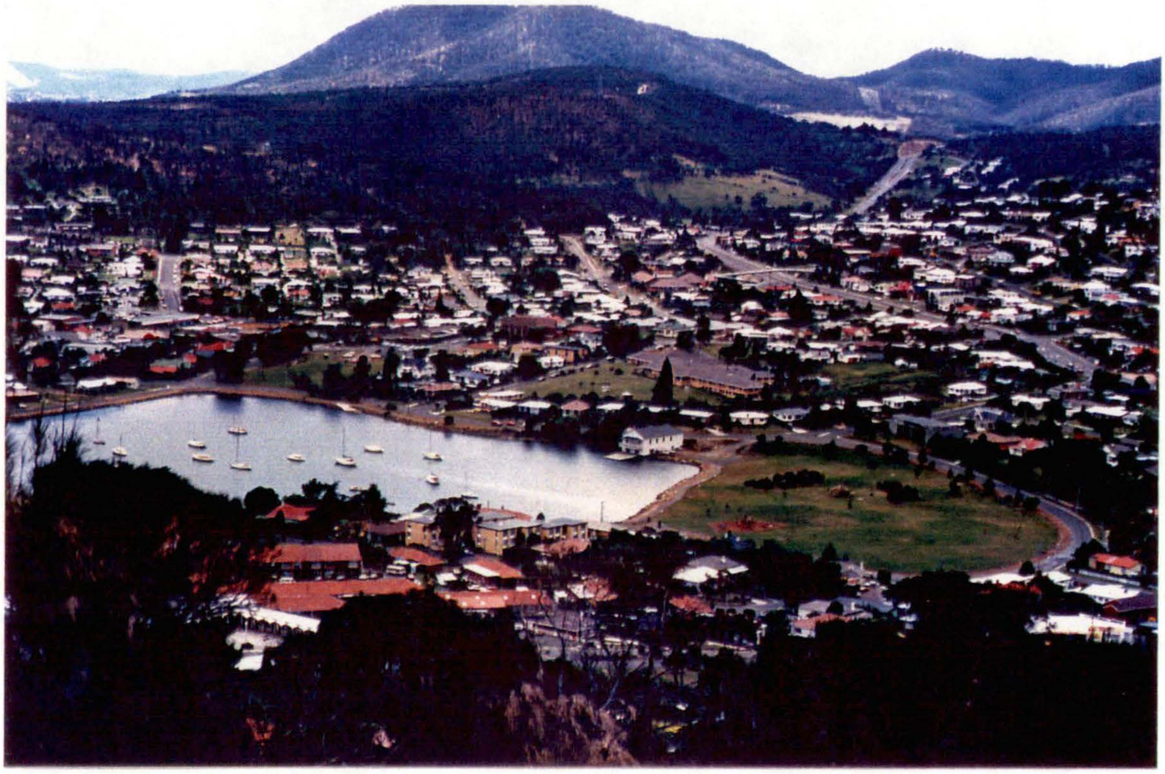


Plate 2.3 Lindisfarne Bay from Gordons Hill, 1988

The reclaimed parkland is today a feature of the bay; however the problem of sedimentation remains and the area in front of the rockwall continues to accumulate sediment.

photo by author

2.4.5 Sewage

Up until about 1940, a night soil collection service operated in Lindisfarne. A horse and cart collected pans from premises and transfered the wastes to a vessel which in turn dumped the waste at sea (Ford pers. comm.).

It was not until after 1940 that septic tank systems were introduced to Lindisfarne. The septic tank itself only treats effluent to the primary or settling stage which has little effect on reducing the bacterial load. Secondary treatment through absorption trenches running along the contour of the land form an integral part of the septic tank system. This latter component of the system was not employed at first in Lindisfarne, hence, effluent was disposed of by connection to stormwater outlets and together with sullage, was disposed of directly into the bay. Although absorption trenches were installed in some instances, the practice of permitting untreated sullage wastes to discharge directly into the bay continued until 1982 when a sewage reticulation system was installed.

Today, sewage from Lindisfarne is pumped from the eastern side of the bay via a pipeline to the adjacent side the bay and then to a sewage treatment works at Risdon Cove approximately 5 km upstream (Fig 1.2). Here it undergoes primary treatment only by sludge digestion. This is not unusual for sewage treatment plants in Tasmania. Secondary treatment is generally lacking. However the treatment works at Rosny does have pilot aerobic treatment facilities.

2.5 Summary of land use history

In summary the major events considered to have influenced the rate and scale of sedimentation in the Lindisfarne Bay area are listed chronologically below. Most have been discussed in preceeding sections, some will be mentioned again in sections to follow.

1838	first European pioneers settled in the area and commenced clearing and tilling the catchment;
1890	original farm estate subdivided for residential development;
1901-1910	Hobart population stabilised and Lindisfarne underwent rapid growth;
1917	EZ Works at Risdon commenced, producing 10 tonnes per day of zinc; liquid effluents discharged to the river;
1922	EZ Works increased production to 100 tonnes per day; liquid effluents continued to be discharged to the river but in greater amounts
1937	Lake St Clair commissioned;
1940	septic tanks replaced night soil collection in Lindisfarne resulting in secondary effluent being discharged to the bay;
1943	floating bridge opened thus connecting Hobart directly with Lindisfarne;
1947-1954	rapid population growth on the eastern shore of the Derwent Estuary resulting in new roads and housing;
1948	annual burning of Natone Hill commenced;

1949	Lake King William Dam commissioned;
1950	sporadic dumping of rubbish in head of bay commenced;
1952	Lake Echo commissioned;
1957	Wayatinah dam commissioned;
1960	Liapootah dam commissioned;
1960	Derwent River in flood (1 in 100 year frequency);
1962	Catagunya dam commissioned;
1964	rock wall built in northeastern corner of Lindisfarne Bay and reclaimation commenced; floating bridge closed and removed and replaced by Tasman Bridge; redirection of Ouse River/Great Lake flow to Poatina
1967	Meadowbank and Cluny dams commissioned;
1967	Repulse dam commissioned;
1969-1970	Natone Hill completed burnt;
1974	new metal recovery process and jarosite dumping commenced resulting in 80 % drop in metal levels of effluents from EZ works;
1975	S. S. Lake Illawarra collided with the Tasman Bridge resulting in collapse of bridge and sinking of ship;
1978	soundings of the bay carried out at request of local sailing club;
1980	1 in 10 year flood of the river;
1981	Contaminated Waste Water system commenced at EZ Works;
1982	sewage reticulation system introduced in Lindisfarne;
1985	Lindisfarne Bay Beautification Committee formed as a result of gross sedimentation;
1986	soundings taken of the bay as part of this study suggest rapid sedimentation rate.

In Lindisfarne Bay, alterations to the catchment of both the river and the bay appear to have accelerated the rate of sedimentation. Associated with rapid population growth between 1947 and 1954 were inappropriate land use practices and the construction of many roads and houses. Annual burning of hills in the catchment, on slopes with low evapotranspiration rates, exposed fragile soils to erosion. Run-off of this material together with road gravels and garden loams has led to substantial deposition of sediment in the bay. Whilst history and its effects on the bay infrastructure cannot be changed, there are obvious warnings for the future not only for Lindisfarne Bay but for the whole Derwent Estuary.

CHAPTER 3

PHYSICAL ENVIRONMENT OF THE STUDY AREA

3.1 Climatic conditions

The Bureau of Meteorology has a rainfall gauge on Gordons Hill enabling monthly rainfall data to be collected for the study area. Temperatures in Lindisfarne are generally within 1°C of those for Hobart so data obtained from Hobart's monitoring station have been used. Wind information has been derived from a wind study of the Derwent Estuary (Pendlebury 1987).

Hobart is the coldest of Australia's capital cities on average with a mean maximum temperature of 21.6°C in February and a mean minimum temperature of 4.4°C in July (Bureau of Meteorology 1988). On average, there are two or three days per year with maximum temperatures greater than 32°C. Minimum temperatures of below -1°C are rare.

The two dominant mesoscale (20-200km) windflows which affect the Derwent Estuary are the katabatic or downslope winds and the sea breeze. Variations in wind velocity are caused by thermal conditions associated with seasonal factors and surface topography. Pendlebury (1987) conducted a wind frequency analysis based on one year's data obtained from seven sites on the Derwent Estuary. The two nearest sites to Lindisfarne Bay mentioned in Pendlebury's study have been used to examine wind patterns in the area. Wind roses (percent frequency) for 0600, 0900, 1200, 1500, 1800 2100 hours combined Eastern Standard Time for the four seasons have been reproduced from Pendlebury's study and are shown in Fig. 3.1. It is apparent that winds come predominantly from the north or northwest upstream from Lindisfarne Bay and are more varied below the bay. Seasonal variations appear not to be significant except in winter and autumn when the northwester is dominant. The strongest wind gusts ever experienced in Hobart were measured at 150 kilometres per hour and these were recorded during a storm in September 1965 (ABS 1986).

The average mean annual rainfall for Lindisfarne is 553mm, based on data for the period 1908-1984 (Bureau of Meteorology 1986). Rain occurs on an average of 73 days per year and December and February apparently have the highest and lowest mean monthly rainfalls of 56 and 40mm respectively (Bureau of Meteorology 1986). Annual averages for the period 1908 to 1984, shown in Fig. 3.2, indicate substantial year to year variation in rainfall. The wettest year in this period was 1956 when 984mm of rain was recorded and the driest was when 261mm fell in 1908. The wettest month on record was December 1985 when 249mm of rain fell, and the driest month recorded was in April 1923 when between 0.1 and 0.4mm fell. The average rainfall for the years

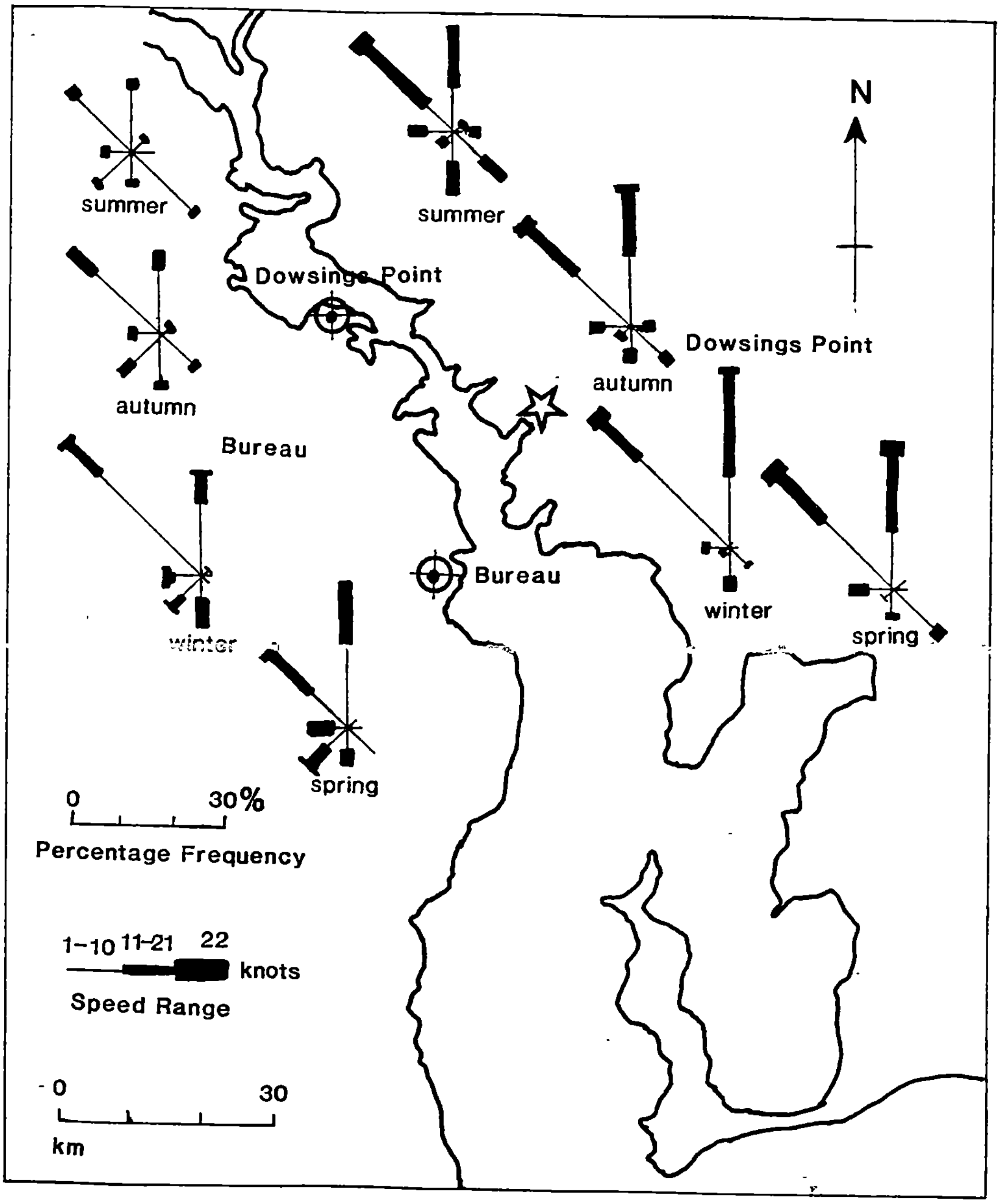


Fig. 3.1 Winds of the Derwent Estuary

The two nearest sites to Lindisfarne Bay (☆) namely Bureau and Dowsings Point are shown; wind roses are the combination of percent frequency for 0600, 0900, 1200, 1500 1800 and 2100 hours Eastern Standard Time; data was recorded during the summer 1984/85, the autumn of 1984, the winter of 1984 and the spring of 1983/84 (November 1983, September, October1984); note that the winds are predominantly from the north and northwest and little seasonal variation exists

source : Pendlebury 1987; map this study

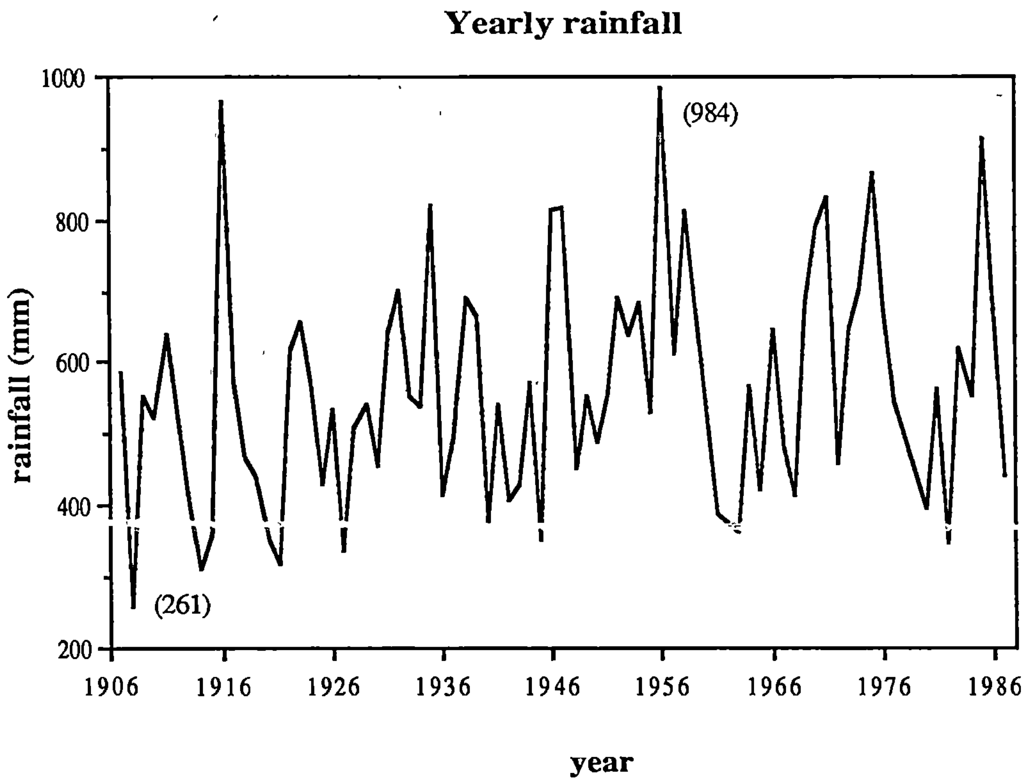


Fig. 3.2 Rainfall for Lindisfarne 1908 - 1984

Data is based on annual average rainfall for the period 1908 to 1984; mean annual average for this period was 553 mm; the wettest year was 1956 (984mm) and the driest year was 1908 (261mm) indicating substantial annual variation; data for the years 1912, 1959, 1960, 1962, 1978 and 1979 were unavailable

source : Bureau of Meteorology 1986

1912, 1959, 1960, 1962, 1978 and 1979 were unavailable. Notably the rainfall of the 1960 floods was part of this incomplete data base.

Snowfalls to sea level have occasionally been recorded in Hobart, the most recent being in July 1986.

3.2 Hydrological conditions

Water levels in the Derwent Estuary can be affected by many factors. Hydrological elements such as floods, slope run-off and evapotranspiration, water currents, and tidal movements all play their part. As well, barometric pressures have a significant influence. Each of these elements are discussed below.

Periods of heavy or intense rainfall can cause extensive floods or erosion. The most severe flood recorded for the Derwent occurred in April 1960 (Australian Bureau of Statistics 1986), when a peak flow of 3500 cubic metres per second (cumecs) of water was recorded at the Macquarie Plains monitoring station (Fig. 2.3). This compares to an average water flow for the Derwent of approximately 110 cumecs, also measured at Macquarie Plains. As mentioned earlier (Section 2.4.2) dams on the Derwent River system have eliminated low water flow rates but have not changed flooding patterns. Rainfall intensity, an important factor in soil erosion, is not discussed in this thesis.

Within the catchment areas of the river and more specifically the bay, heavy rainfall can also create extensive run-off which may carry a sediment load into the bay. In order to estimate the levels of suspended matter in run-off from the catchment, discharge from a stormwater pipe located in the northwest corner of the bay was sampled by the author in the spring of 1987 during a flash storm lasting about 20 minutes (Fig.3.3). The highest level recorded was 695 mg/l indicating that during that storm substantial sediment was entering the bay from this area.

It was desirable, but beyond the scope of this work, to estimate flow rates and subsequent sediment loadings into the bay over time as stormwater drains are a major contributor of sediment to the Bay.

Solar radiation is also an important parameter when considering potential run-off from slopes. It would be expected that solar energy received on north facing slopes would be greater than on south slopes hence there should be a nett difference in evapotranspiration. Generalised models to evaluate solar radiation received on slopes in Tasmania have been developed (Nunez 1980, Nunez 1983), which involves the use of cloud cover data to determine the incidence of direct and diffuse solar radiation on a tilted surface of any orientation, limited by sky factor and shadow effects.

The model developed by Nunez has been applied to the southeast slope of Natone Hill and the northwest slope of Gordons Hill, both in the catchment area of Lindisfarne Bay. Significant variation in net solar radiation on the different slopes emerged. The ratio of the yearly solar radiation incidence on Gordons Hill to that incidence on Natone Hill for the two slopes was 1.3:1.

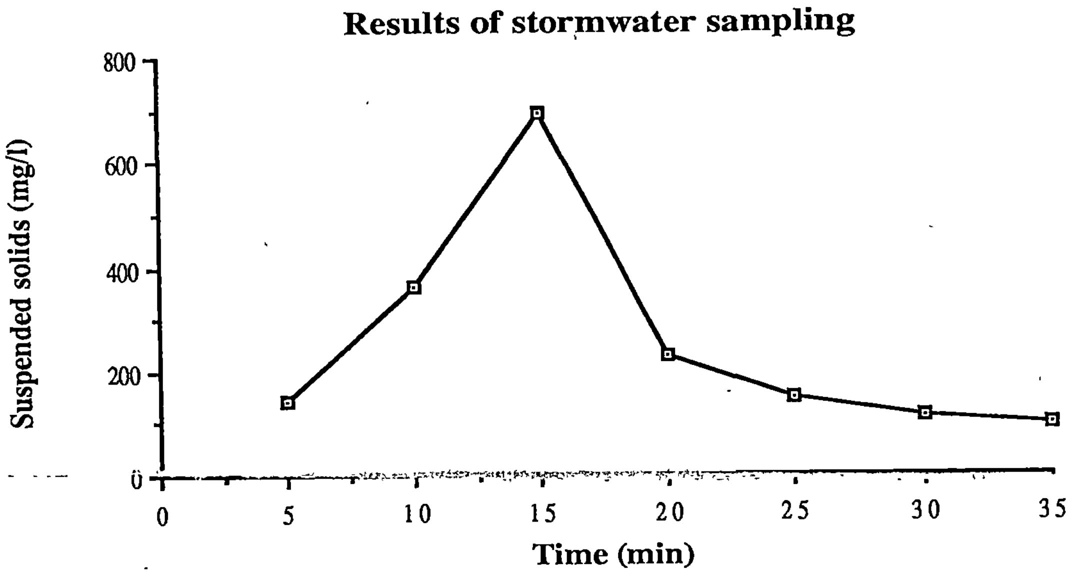


Fig. 3.3 Suspended sediment entering the northwestern corner of Lindisfarne Bay

Samples were taken from a stormwater pipe (diameter 0.6m), located in the northwestern corner of the bay during a flash storm lasting about 20 minutes in the afternoon of the spring of 1987; the highest recorded level of 695 mg/l suggests substantial sediment was entering the bay at this point

analysis : courtesy Government Analyst, Hobart

The ratio of the rate of mean daily solar radiation received on the same two hills was 1:0.2 in December (summer) and 1.7:1 in June (winter). In spring and autumn, net solar radiation received was intermediate between values obtained for winter and summer.

The results of stormwater sampling could not be related directly to evapotranspiration rates because only one slope was sampled. Nevertheless, the varying rates of evapotranspiration do play a key role in determining potential run-off from slopes in latitudes akin to those of the study area.

From heavy metal levels found in a survey of mussels in the Derwent River carried out by the EZ Company, surface water movement was predicted by Cooper et al. (1982). These authors postulated that while metal concentrations in shellfish were initially high in the estuary area they decreased with distance down the coast, following the path of major surface currents from the source of contamination (EZ). It was also suggested that lower metal concentrations in shellfish in some areas adjacent to the Derwent Estuary were due to the ingress of water from contaminated sources.

It is beyond the scope of this study to examine the currents of Lindisfarne Bay in detail. However, currents in the Derwent have magnitudes of from one to five knots to seaward off Rosny, adjacent to Kangaroo Bay, which is approximately two kilometres to the south of the study area (Fig 1.2). In Lindisfarne Bay itself, currents are considered to be negligible (Godfrey pers. comm.).

Ong (1967) when studying the primary productivity and zooplankton distribution on the surface waters of the Derwent Estuary, noted that 'the knowledge of circulation patterns is extremely inadequate.' He also stated that

> 'this inadequacy is further aggravated by the replacement of the Old Hobart Pontoon bridge (referred to as the floating bridge in Section 2.2) by the Tasman Bridge in 1965 as well as by the construction of various dams up river for hydroelectrical and agricultural purposes.'
>
> Ong (1967)

Ong (1967) concluded that these factors would have caused considerable changes to the hydrological regime of the estuary as evident by viewing aerial photographs (see Plate 1.2).

Apart from this and earlier work by Guiler (1952), several studies have been carried out of tidal movement in the estuary (Guiler 1952, Ritz & Buttermore 1984, Thomson & Godfrey 1985) and of water movement (Cooper et al. 1982). These studies indicate that the tidal range of the Derwent extends from New Norfolk to Opossum Bay on the eastern side of the river (Fig. 1.1). It should be also remembered that the lower part of the Derwent River Valley has been inundated by the sea since glacial times and that the distance freshwater extends down the estuary during flood periods is greater on the eastern side than on the western side (Guiler 1952). Also, there is a small tidal flow at Hobart averaging 550mm per annum.

The river tends to follow a classical salt wedge estuary condition in winter when freshwater flows closely match the tidal prism. In summer, partial mixing tends to occur and the ratio of freshwater to salt water is approximately 1:3 (Ritz & Buttermore 1984).

The halocline depth along the river can change over periods of a few hours in association with tides. Salinity depths along the Derwent indicate that Lindisfarne Bay consists primarily of salt water during summer when rainfall and river discharge is lowest (Guiler 1952, Thomson & Godfrey 1985). In winter, however, the bay appears to become stratified and salinity levels of as low as five percent have been recorded on the surface at the mouth of Lindisfarne Bay. Also a salt water wedge has been recorded at a depth of four m (half the depth at the site of recording) (Thomson & Godfrey 1985).

The tidal range, as taken from Hobart (550mm) is small so the mixing caused by the tide in the Derwent is considered not to be important volumetrically. It is suggested that surface stirring by wind is the primary mixing mechanism in the estuary while tidal mixing plays a small but perceptible part (Thomson & Godfrey 1985). This is also the most likely case in Lindisfarne Bay.

Wind generated waves could be estimated from wind roses (section 3.1) and off-shore tidal movement. However the wind data applies to other parts of the estuary and the local wind pattern in Lindisfarne Bay would need to be obtained in order to construct wind patterns for the bay.

3.3 Topography & geology

The catchment of Lindisfarne Bay takes in three hilltops extending to a maximum height of approximately 160 m and each hill has a different geological formation. The catchment covers an area of approximately three square kilometres being bounded by the ridgelines of Natone Hill and Gordons Hill and extending back to the summit of Pilchers Hill (Fig. 3.4). The slopes of Natone Hill and Gordons Hill have grades of up to 1:4. The southeast slope of Natone Hill and the northeast slope of Gordons Hill drain directly into Lindisfarne Bay . The bay has a water surface area of approximately 0.21 square kilometres (Fig. 3.4).

The geology of the Hobart district has been fairly extensively studied (Department of Mines 1945, Lewis 1946, Leaman 1976). The Lindisfarne region has also been studied in detail primarily to ascertain prospects of underground water (Department of Mines 1945). Of the three different geological formations in Lindisfarne, the oldest exposed rocks are of Permian age and are comprised of an intermittently fossiliferous siltstone-mudstone sequence. Triassic sandstone and Jurassic dolerite make up the stratigraphy of Lindisfarne (Fig. 3.5).

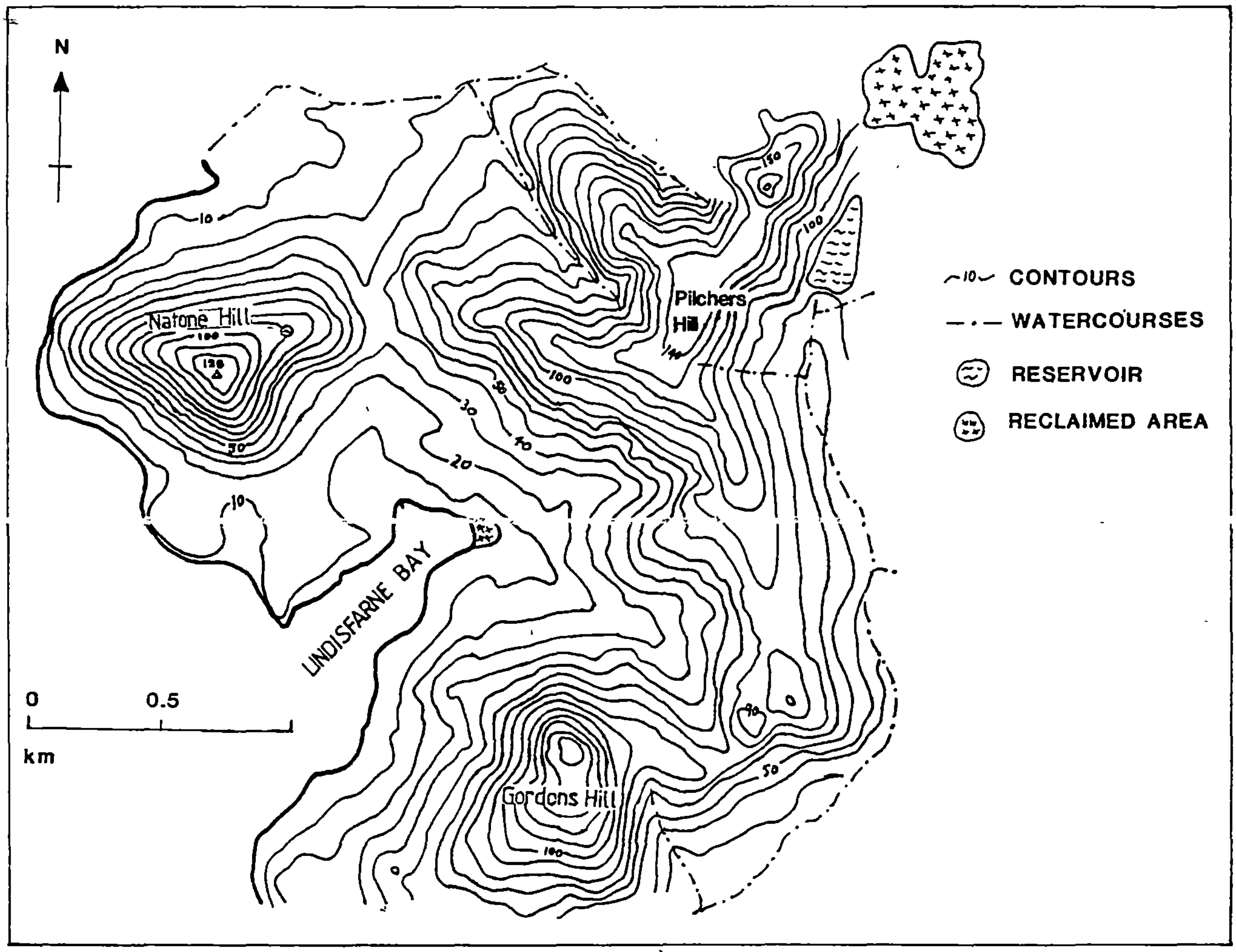


Fig. 3.4 Topography of the catchment of Lindisfarne Bay

The bay covers an area of approximately 0.2 km² while its catchment covers an area of approximately 3km². The slopes of Natone Hill and Gordons Hill which drain into the bay have grades of up to 1 in 4.

source : Lands Dept. Tasmania, 1985, 1:25000 series Hobart

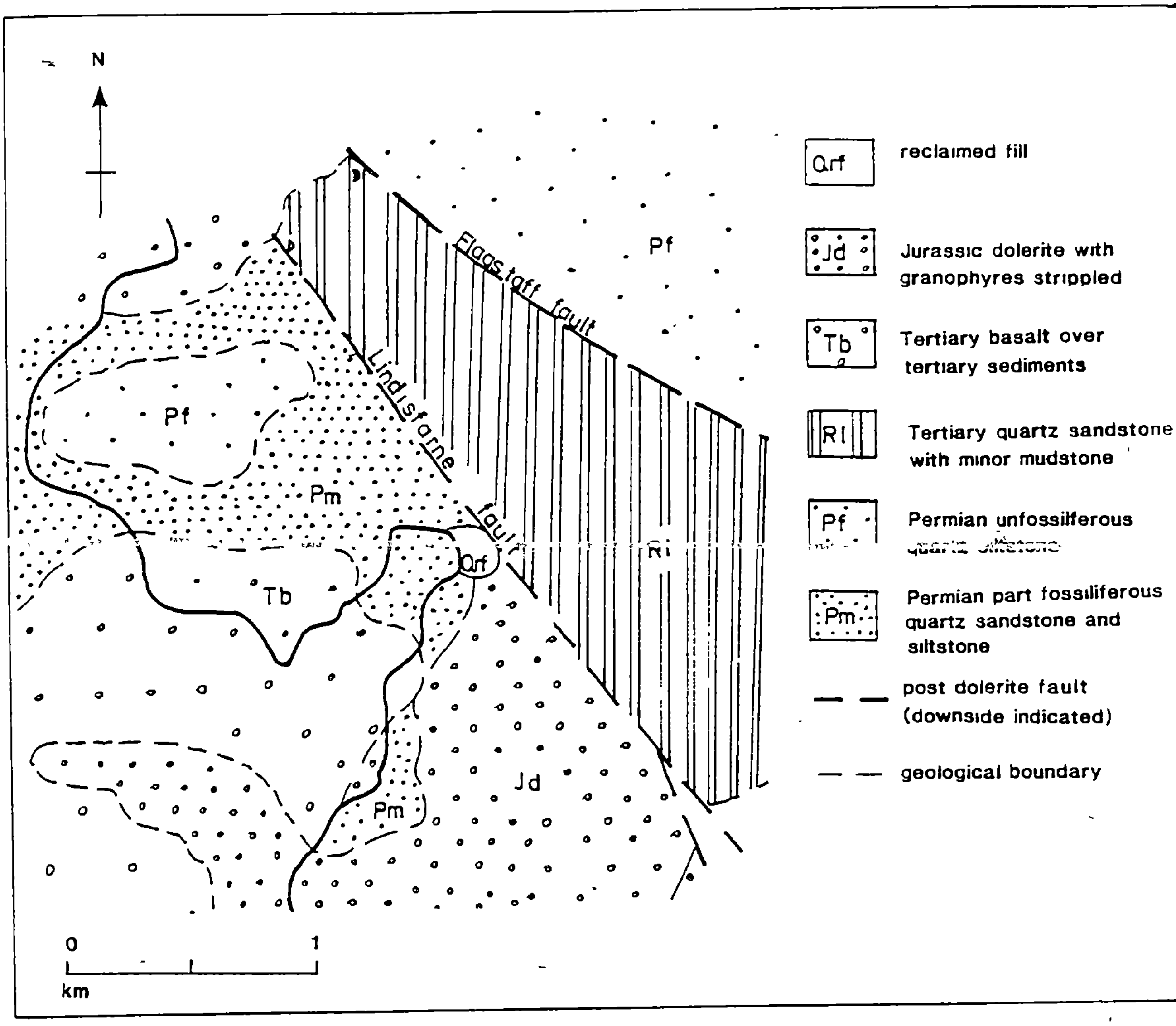


Fig. 3.5 Geology of the Lindisfarne region

Three distinct geological formations occur; the oldest being Permian intermittently fossiliferous quartz siltstone and sandstone; Triassic sandstone and Jurassic dolerite make up the stratigraphy; an important feature includes the reclaimed fill

source : Leaman 1976

Two fault lines feature in the geology of Lindisfarne. The Lindisfarne Fault has Lindisfarne sandstone to its east and extends southwards into Bellerive sandstone. The Lindisfarne sandstone appears to be normal Spring Sandstone mostly massive but with some shaly layers. The sandstone rises from sea level to a height of about 120 metres. Southwards, it is brought into juxtaposition with dolerite. The Flagstaff Fault occurs where the boundary of the southern extension of the Risdon Mudstone lies.

An important feature is the reclaimed fill at the head of Lindisfarne Bay (Plate 2.3) (refer to section 2.4.4) .

3.4 Soils and vegetation

The three distinct geological formations in the Lindisfarne Bay catchment have resulted in different soils and vegetation. Consequently, three separate land systems have been identified in the catchment (Fig. 3.6).

The concept of a land classification system was developed in Australia by CSIRO on the premise that resources are the result of an interaction between geology, climate, topography, vegetation and soils. A land system area has been formulated when the above primary factors reoccur. The system has been designed to present complex land resource data in a digestible form enabling the formulation of wiser land use policies and the identification of potential hazards in land management (Davies 1987).

The three land systems occurring in the catchment of Lindisfarne Bay are known as Government Hills, Heathy Hills and Stony Hills and include Natone Hill, Pilchers Hill and Gordons Hill respectively (Fig. 3.6).

Natone Hill, falling within the system known as Government Hills, contains extremely shallow (<0.25m) stony but fine sandy loam developed on bedrock at its exposed crests and upper slopes. These soils support a woodland dominated by <u>Eucalyptus globulus</u>, <u>E.</u> <u>amygdalina</u> and <u>E. tenuiramis</u>. The understory includes <u>Lomandra longifolia</u>, <u>Exocarpos cupressiformis</u>, <u>Acacia dealbata</u>, <u>Astroloma humifusum</u>, <u>Leptomeria drupacea</u> and <u>Poa</u> species (Davies 1987) (Plate 3.1). However the hazard reducing fires discussed in Chapter 2 appear to have burnt away most of this understorey. Flat topped crests in this system have a slightly deeper soil (<0.4m). The vegetation differs in the understory from the exposed crests and upper slopes and <u>Viola hederacea</u>, <u>Comesperma volubile</u>, <u>Lissanthe strigosa</u>, <u>Dodonaea viscosa</u>, <u>Acacia mearnsii</u> and <u>Bursaria</u>

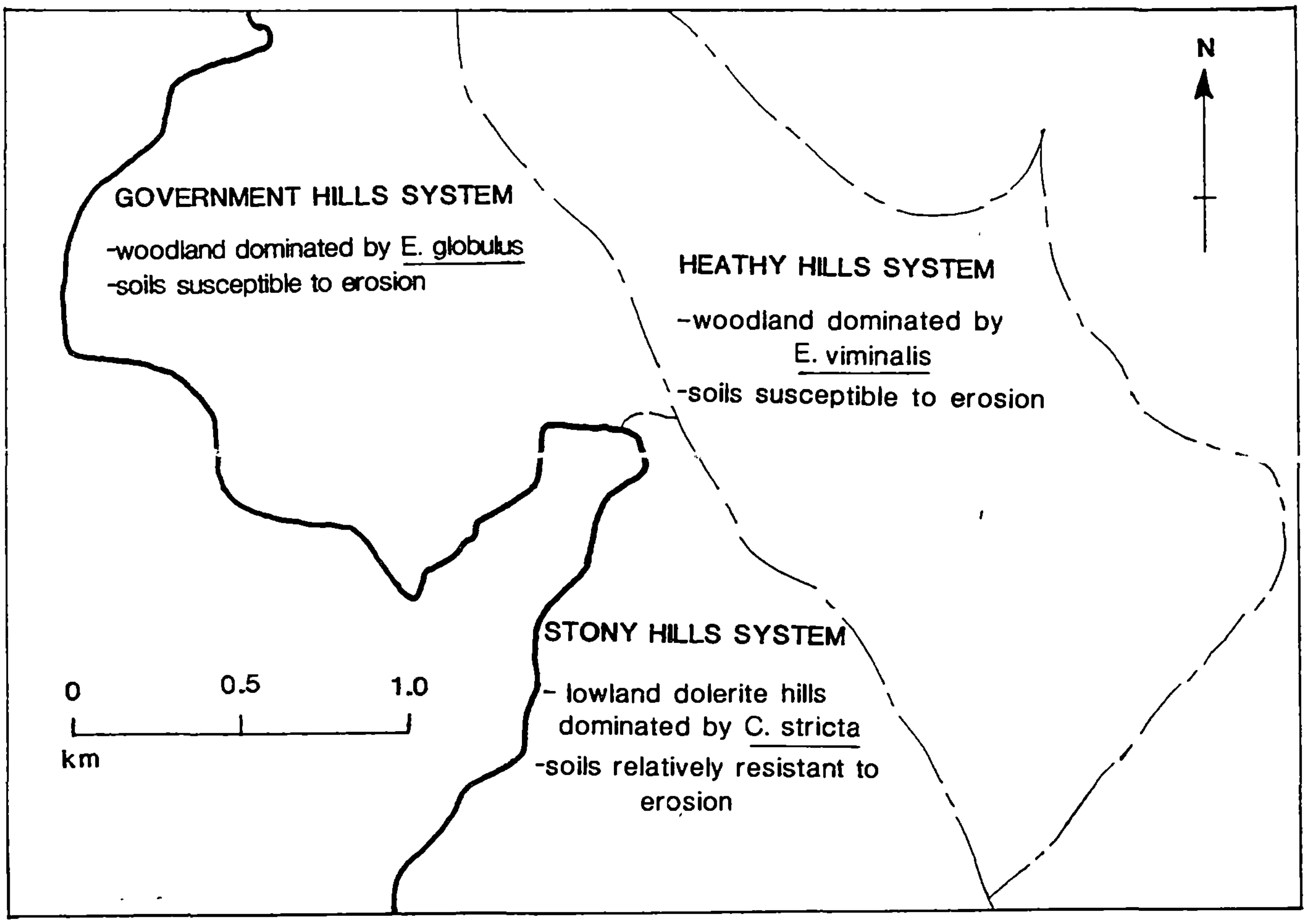


Fig. 3.6 Land systems of the Lindisfarne region

A land sustem area is the reconcurrence of the following five primary factors: geology, climate, topography, vegetation and soils; the study area contains three different systems of which salient features are shown

source : Davies 1987; map 1988

spinosa also occur (Davies 1987). On mid and lower slopes, a deep (>0.7m) duplex soil is common. This consists of a fine sandy loam on the surface becoming a light yellowish brown or brownish grey clay.

Protected lower slopes are dominated by the same species as occur on the upper slopes as well as E. obliqua and the understorey includes a variety of other species. The flats of this system, including the area in and around Natone Hill have a deep (>1.1m) duplex soil, consisting of a fine sandy loam on the surface over a grey medium clay that sometimes contains a light olive mottle at depth. This soil supports a woodland dominated by E. ovata over Melaleuca squarrosa (Davies 1987).

The soils of this land system are known to be particularly susceptible to erosion. Those on crests and slopes in particular being highly prone to sheet and rill erosoin. Gully, streambank and tunnel erosion are also hazards on the lower slopes and flats while flooding and water logging are common problems along drainage lines (Davies 1987).

The second land system occurring in the catchment area is the Stony Hills land system, which includes Gordons Hill (Plate 3.2), and is dominated by dry lowland dolerite rises (Fig. 3.6). Crests and upper slopes are covered by an extremely shallow (< 0.2m) stony clay loam developed on bedrock that supports a low woodland dominated by Eucalyptus viminalis , Casuarina stricta , A. mearnsii and A. dealbata with a grassy understorey.

The crests and lower slopes are relatively resistant to erosion, although drainage lines are susceptible to gully erosion. Flooding and water logging occur on drainage flats (Davies 1987). Pilchers Hill (Plate 3.3) occurs in the Heathy Hills land system which is made up of the land running from further north at Risdon to southeast of the catchment (Fig. 3.6). Soils are slightly shallower than those occurring in the Government Hills land system and support similiar open woodland with the addition of E. viminalis .

The soils of this land system are also particularly vulnerable to erosion with rill, streambank and gully erosion frequently occurring on the lower slopes and flats. Waterlogging and flooding are also potential hazards on flats and along drainage lines (Davies 1987).

Plate 3.1 Natone Hill 1987

The photograph shows the southeast slope of Natone Hill where ^{137}Cs samples were taken; the area on the left shows long grasses under a canopy of Acacia and the area on the right shows short grasses and a canopy of Eucalyptus indicating different fire patterns for different parts of the hill

photo : author

Plate 3.2 Gordons Hill 1987

The photograph shows the upper northwestern slopes of Gordons Hill where ^{137}Cs samples were taken; the hill features dolerite outcrops and is dominated by Casurina stricta

photo : author

Plate 3.3 Pilchers Hill 1987

The flat summit of Pilchers Hill features an open canopy of E. viminalis; input values for ^{137}Cs were undertaken

photo : author

3.5 Measurements of water depth

Record of soundings of the Derwent Estuary appear to be sparse. Lindisfarne Bay itself has been measured only occasionally. In 1978, the inner part of the Bay was sounded at the request of the Lindisfarne Bay Sailing Club. As part of the work reported in this thesis, measurements have been carried out during 1986 for the whole bay area (Fig. 3.7). A summary of the methodology used to obtain the soundings accompanies the contour map.

As can seen from Fig. 3.7, the western side of Lindisfarne Bay falls away to a depth of three to four m fairly quickly while the eastern side has a much gentler slope. At the same time, the northwestern and northeastern corners of the bay both show large deposits of sediment. Small ridges on the slopes continue as shallower waters in the bay, perhaps evidence of sediment deposition.

As far as was possible, the soundings recorded in 1978 have been compared with the more recent ones taken in 1986. This comparison, restricted to the head of the bay, since the 1978 study covered this area only, is shown graphically in Fig. 3.8. In this comparison, measurements are shown in metres above Chart Datum Level. As can be seen from Fig. 3.8, the two sets of sounding records, taken a mere 8 1/2 years apart, indicate substantial changes in depth in that time of about 0.3 m.

3.6 Aquatic flora and fauna

Several aquatic plant species are present in Lindisfarne Bay. One of particular interest is Enteromorpha intestinalis which is widely distributed in the intertidal zones of marine habitats where it grows on rocks, woodwork shells, and other algae (Bold & Wynne 1985). It has a wide distribution and has been located at seven m depth in sewer outfalls in South Australia and in upper eulittoral pools in the Derwent Estuary (Womersley 1984).

As part of the work reported in this study aquatic fauna presently found in Lindisfarne Bay have been determined by sampling bottom sediments using a Petterson Grab at several locations across the bay (Fig. 3.9). Thirty five samples were collected of which eight contained specimens of aquatic fauna. The most common invertebrates found were Ostrea angasi (the common mud oyster), and Patiriella regularis (the cushion star). Patiriella regularis was introduced from New Zealand some time after 1930, and is now widespread in southeast Tasmania (Green pers. comm.). Other fauna occurring in smaller numbers were identified as Amarinus laevis and Halicarcinus ovatus (spider crabs), Nassarius nigellus (dog whelk) Echinocardium cordatum (sea urchin), and Lumbrineris sp. (a species of marine worm) (Green pers. comm.).

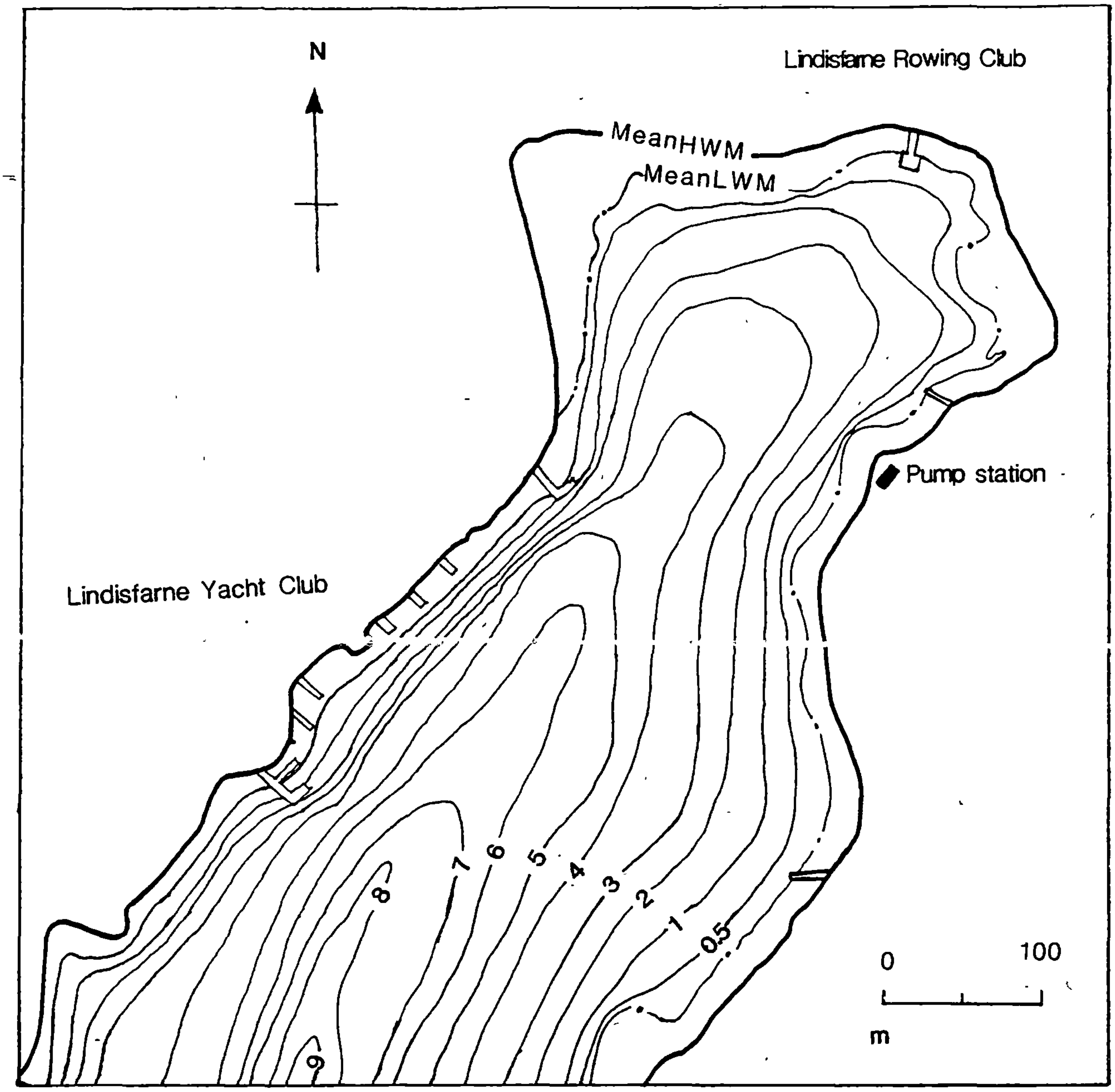


Fig. 3.7 Soundings of Lindisfarne Bay 1986

As part of the study soundings were recorded between 10am and 3pm on August 19, 1986; measurements were taken several metres apart from a boat along eight transects across the bay; a shore based person equipped with a vertical compass synchronised measurements with the boats location; measurements were converted to Chart Datum levels and from these values the contour map was drawn

source : this study

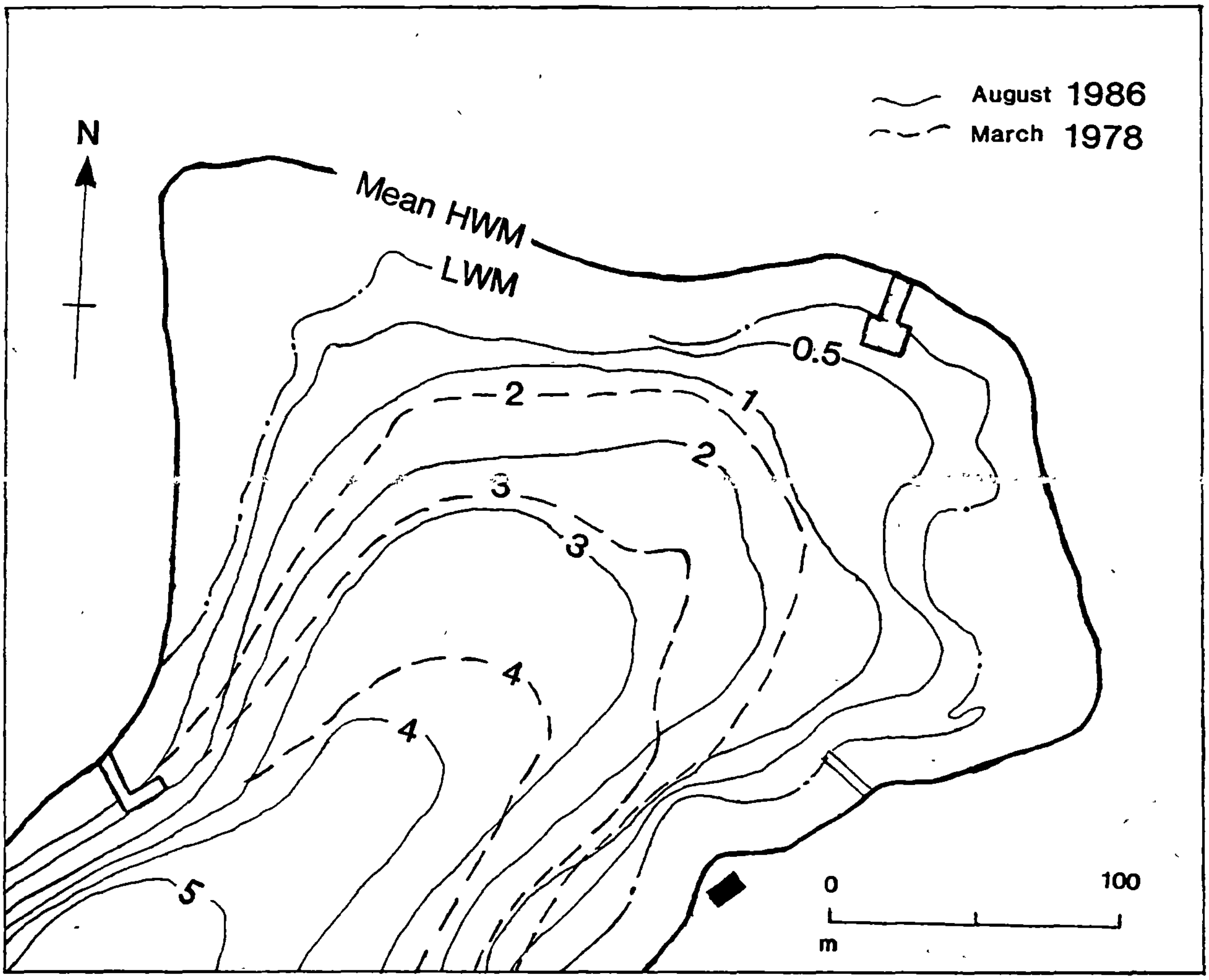


Fig. 3.8 Soundings of the head of the bay 1978 - 1986

Soundings taken as part of this study on August 19, 1986 (see Fig 3.7) were compared with soundings taken on March 9, 1978 by the Marine Board of Hobart; it is evident in this 81/2 year period that a substantial amount of material has deposited

source : Marine Board of Hobart & this study

Some species of aquatic fauna once present in upstream bays of the Derwent Estuary can no longer be found there. Dredging in New Town Bay, for example, used to yield bivalve molluscs in the Family Pectindae, which are typical of a sandy bottom. Similarly, Prince of Wales Bay (Fig. 1.1), used to yield specimens of Echinocardium cordatum. As well, in earlier times, oysters and scallops used to be found together with other marine species (Guiler 1952). It appears that since the 1950s the once sandy bottom of Lindisfarne Bay has become very muddy and that the of aquatic fauna now found there are typical of a muddy habitat.

Guiler (1952) has suggested that changes in the substratum of the benthos, from sand to mud resulting from increased sediment deposition, have altered the aquatic fauna of bays in the Derwent Estuary. The preliminary examination of the benthic fauna in Lindisfarne Bay, shown above, concurs with Guiler's suggestion.

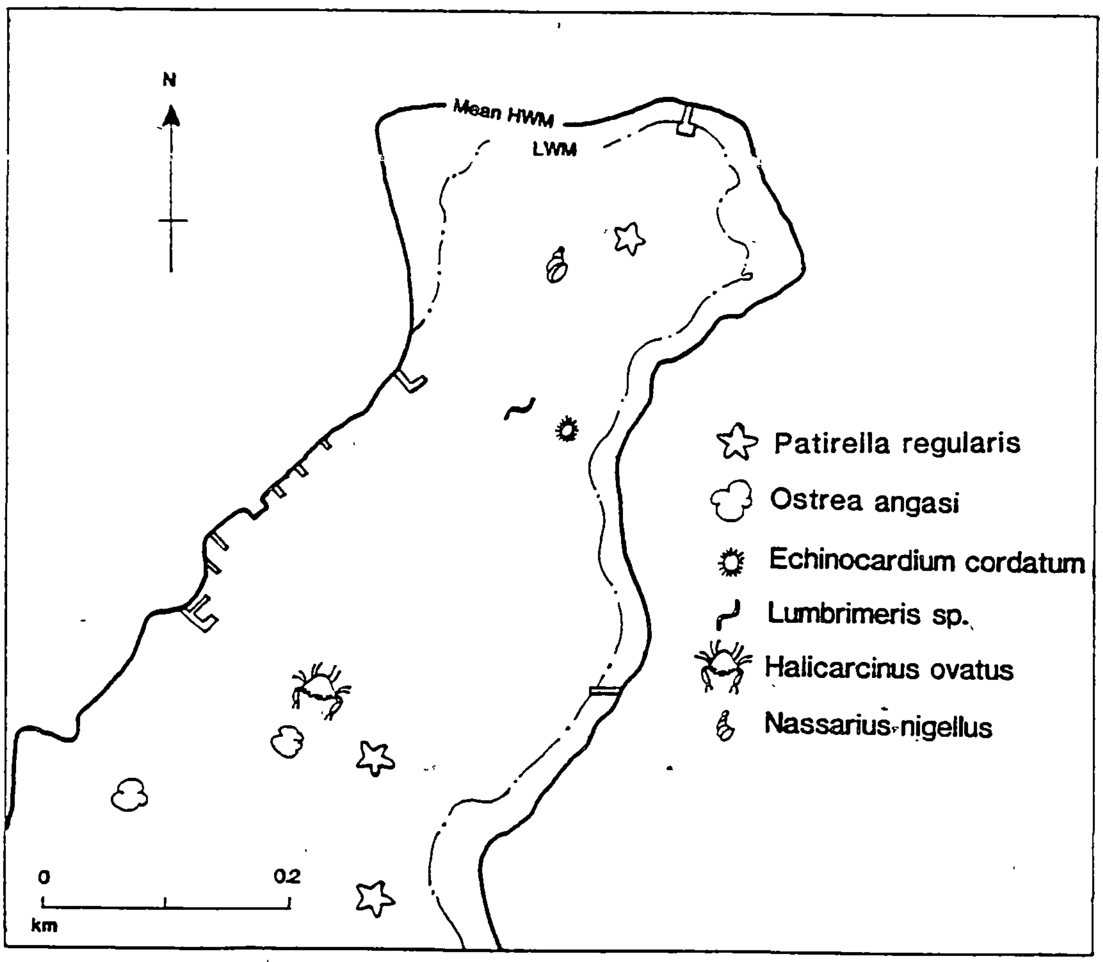


Fig. 3.9 Survey sites of sediment fauna

As part of this study, samples of bottom sediments were taken using a Patterson grab at various locations in the bay; samples containing aquatic fauna were at locations shown in the diagram; identification courtesy A. J. A. Green

map : this study

3.7 Water quality

Factors likely to affect water quality of Lindsfarne Bay are:

(a) sedimentary deposits eminating from run-off in the surrounding catchment;

(b) sewage discharges from the outfalls at Rosny and Risdon Vale sewage works (Fig. 1.2);

(c) industrial effluent coming from industries, the main one being EZ at Risdon; and

(d) leachate from the reclaimed tip.

Criteria for assessing these factors include:

(a) bacteriological counts of indicator organisms;

(b) heavy metal concentrations;

(c) nutrient levels ; and

(d) pesticide concentrations.

This is not an exaustive list and as this study is concerned with examining the sediments in Lindisfarne Bay, assessment of the water quality is confined to existing data only. There is no data available on nutrient levels and pesticide concentrations in water from Lindisfarne Bay.

The Clarence Council has been monitoring bacterial levels in the bay as part of a routine program of sampling of recreational waters throughout the municipality. As well, the Tasmanian Department of Environment has been sampling the waters of the Derwent Estuary for metal concentrations since 1974. These two criteria are discussed.

Whilst Hart (1974) suggested that no available routine bacteriological examination can establish with certainty the presence in water of pathogenic microorganisms, he stated that the presence of biological indicator organisms are accepted as the current most practical means of determining the hazards associated with the use of water. The most commonly used indicators are Escherichia coli and faecal coliforms. It has been established that E. coli counts can vary dramatically depending upon the time of sampling and tidal conditions in saline waters. This limitation subsequently imposes a considerable variation in bacterial levels over time.

The United States Environment Protection Agency (USEPA), as required by legislation, publishes criteria for water quality accurately reflecting the latest scientific knowledge (USEPA 1986). These bacteriological water quality criteria have been based on an estimate of bacterial indicator counts and gastrointestinal illness rates. The work has indicated that enterococci are a more accurate indicator of faecal pollution than E. coli for marine waters, while either E. coli or enterococci may be used as indicators of pollution of fresh waters.

Guidelines for recreational use of water in Australia have been formulated by the National Health & Medical Research Council (NH & MRC 1987). The indicator used is the faecal coliform group and the guideline for primary contact recreation, referred to as swimming, diving, water skiing and surfing, is a median value not exceeding 150 organisms per 100 ml for a minimum of five samples taken at regular intervals not exceeding one month and with four out of five samples containing less than 600 organisms per 100ml.

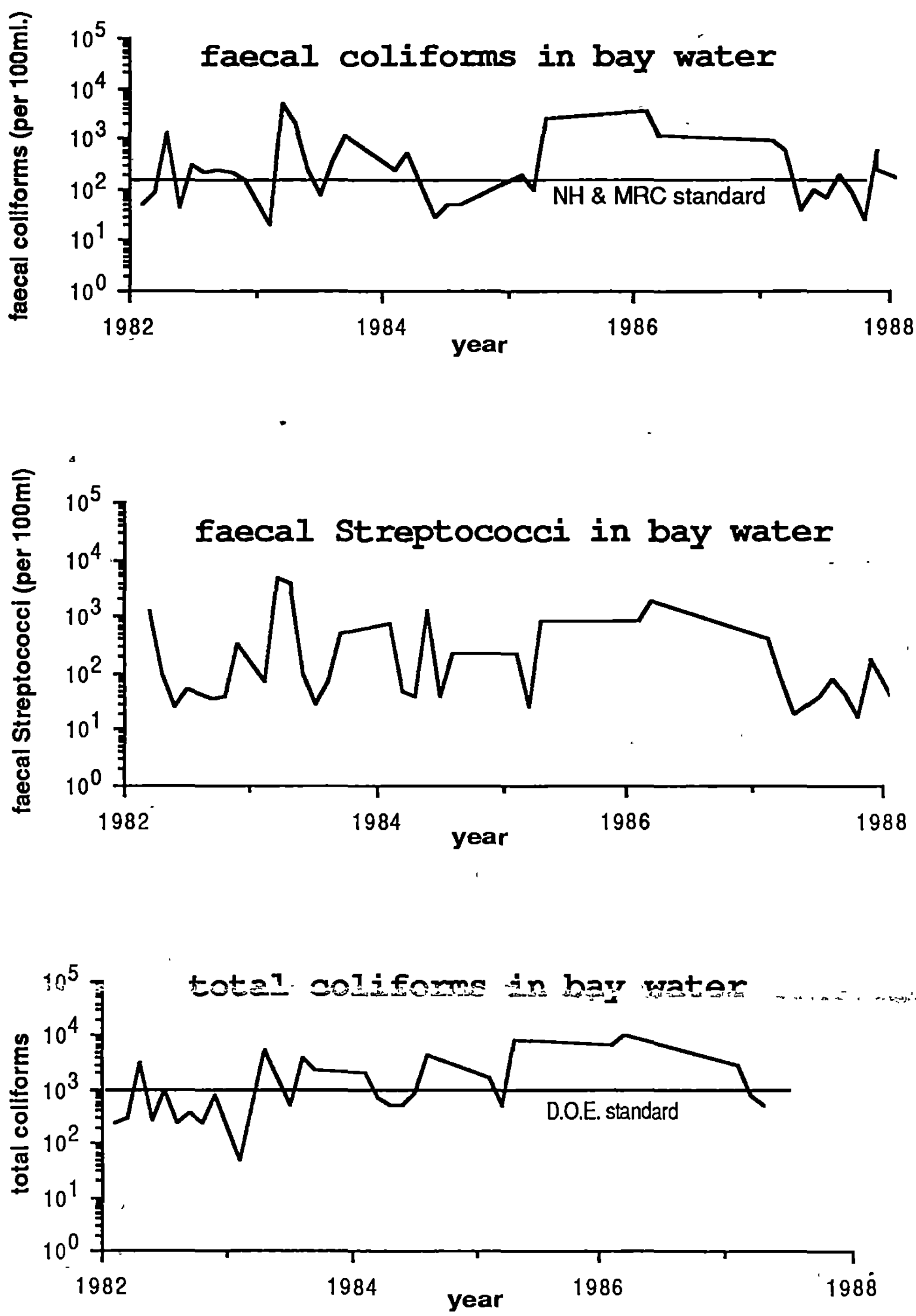
Hart (1974) has also suggested bacterial standands for Australian contact recreational waters. According to Hart (1974), if the level of 200 faecal coliforms per 100ml is approached or exceeded regularly during the recreational season, then action ought to be taken by the relevant authority to assess the possible health risk. A full sanitary survey would be required to assess the sources of pollution. As well, analysis for the presence and concentration of pathogenic bacteria and viruses would also be necessary. Locally, the Tasmanian Department of Environment (DOE) has formulated guidelines for Tasmanian recreational waters which include bacterial standards. The DOE has used E. coli and total coliforms as indicators of faecal pollution. As the DOE standards are set for local waters, they have been adopted for reference in this study. However, in light of the recent advances in water quality criteria, USEPA 1986, the standards set for Tasmanian waters especially marine waters, ought to be reviewed and updated. The NH & MRC standard for faecal coliforms has also been used as a reference in this study. Enterococci has not been used because data was not available. The adopted standards are presented in tabular form below.

Table 3.1 Bacterial Standards for Recreational Waters

	Coliforms per 100 mls		
	E. Coli	*total coli's*	*faecal coli's*
Primary contact	200 (1)	1000 (1)	150 (2)
(bathing, swimming etc.)			200 (3)
Secondary contact	1000 (1)	unlimited (1)	1000(2)
(sailing, fishing etc.)			

Sources : 1 Department of Environment Tasmania 1986b
2 National Health & Medical Research Council 1987
3 Hart 1974

Results of analysis of bacterial levels in water samples from Lindisfarne Bay are shown graphically in Fig. 3.10. All the samples discussed herein were taken in daylight and were submitted for analysis within a few hours of sampling. Several interesting features are shown in Fig. 3.10.



3.10 Bacterial levels in water from Lindisfarne Bay 1982-1988

Bacteriological analyses of water samples were carried out by the Government Analyst and obtained off the jetty on the western side of the bay by municipal Health Surveyors; all samples were collected during the day; sampling was infrequent but usually monthly during summer and bimonthly in winter

source : Clarence Council Health Department

Firstly the DOE standard for total coliform counts for primary contact waters and the NH & MRC guidelines for faecal coliforms have been exceeded regularly between 1982 and 1988, the period when monitoring occurred. Secondly levels of faecal coliforms, faecal Streptococci and total coliforms in samples taken from the bay show erratic levels over the period of sampling.

The erratic levels of the three coliform groups tested for water samples taken in the bay maybe due to escape of sewage from the sewer line near the pump station on Esplanade, Lindisfarne (Fig. 3.7). On answer to a question on this topic in the Tasmanian House of Assembly, the Minister for the Environment quoted a report prepared for the DOE by the Clarence Council thus:

> ...the rising main from the pump station on the Esplanade near Ballawinnie Road appeared to be leaking (6am September 29, 1988). Inspection confirmed this to be so with sewage filtering to the ground. The main was still functioning so it was left in that state until the peak flow period had passed to minimise the discharge into the bay which was inevitable whilst repairs were undertaken.
>
> (Hansard 1988)

Escape of sewage from the pump station has occurred previous to the occasion cited above as testimonied by local residents. The erratic bacterial levels reported therefore may be attributed in part to a leaking pump station.

In examining sewage pollution of the bay area it should also be kept in mind that unchecked sewage discharging into Lindisfarne Bay may be traced back to earlier methods of disposal (ie septic tanks), and that effluents were sometimes directly discharged into the bay via stormwater systems proir to 1982. Since that time a reticulated sewage scheme, as discussed in section 2.4.5, has been in operation .

With respect to heavy metal pollution of the waters of Lindisfarne Bay, no direct data are available. The nearest sampling sites to Lindisfarne Bay within the Tasmanian Department of Environment Derwent River Monitoring Program are at Cornelian Bay and Tasman Bridge (Fig.1.1). Concentrations of the metals Cd, Cu, Pb and Zn in these waters as determined by the Department for the period 1974 to 1987 are shown graphically in Fig. 3.11.

The number of sampling occasions varies from three to six per year and analysis was carried out on filtered (>0.45 micron) water using a weak acid extraction of 3mL concentrated nitric acid per litre of water. As can be seen from Fig. 3.11, mean concentrations of Cd, Cu, Pb and Zn in water samples have decreased since 1974. It should be noted (see section 2.4.1) that this coincided with the time when measures were taken by the EZ company to reduce the heavy metal pollution in the Derwent River.

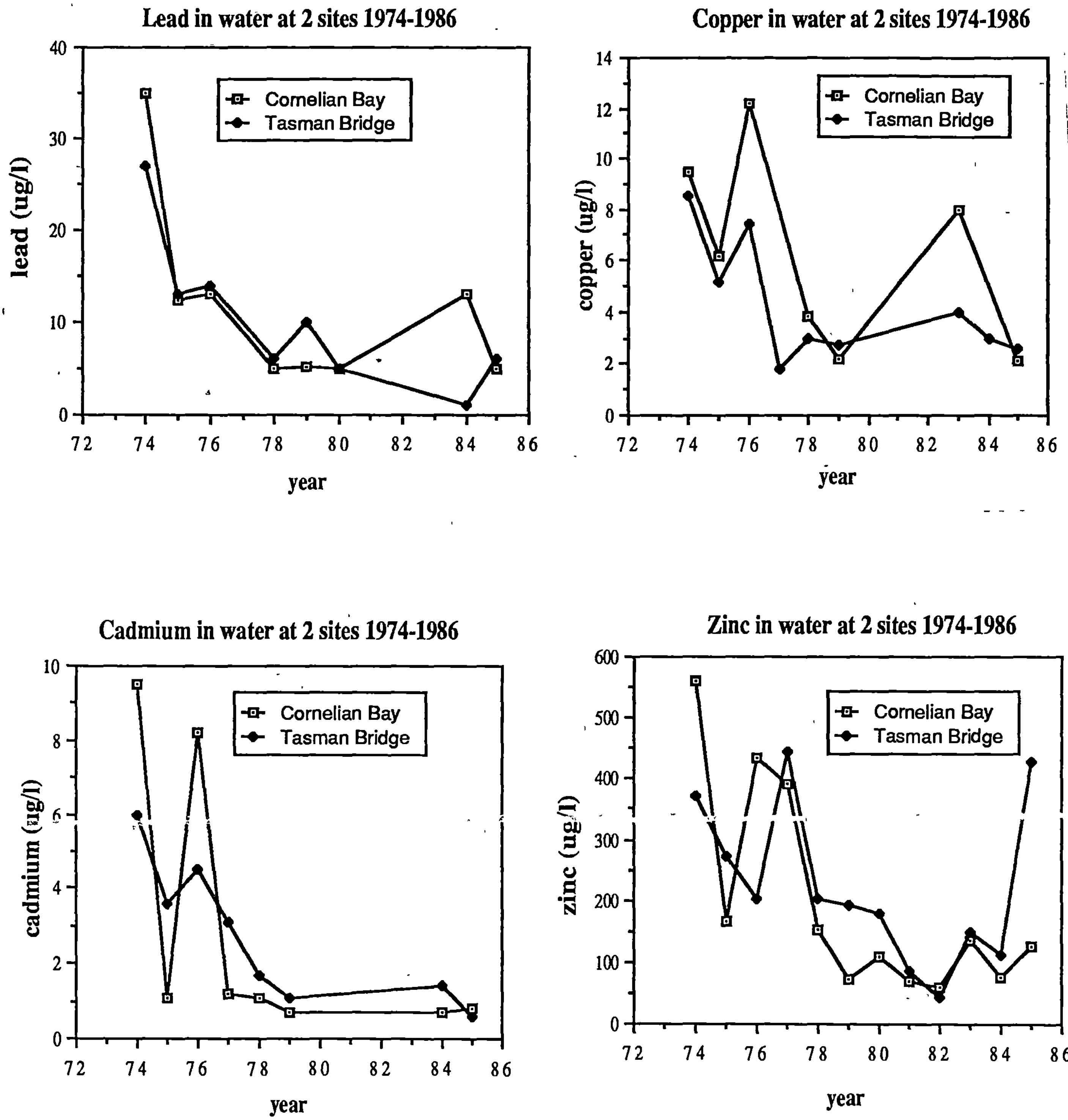


Fig. 3.11 Heavy metals in water from two sites in the Derwent Estuary 1974 - 1985

Cd, Cu. Pb, and Zn concentrations from Cornelian Bay and Tasman Bridge, the two closest sampling sites to Lindisfarne Bay; the values are mean values from three to six sampling occasions per year and analysis was peformed on filtered water; note the general decrease in all metals since 1974

source : Dept of Environment Annual Reports 1973 to 1987

Copper and lead levels showed fluctuations in the period following the mid seventies drop. A contributing source of these metals apart from EZ and the sewage treatment works could well be related to wash-off from roads during periods of heavy rainfall. The higher zinc levels in the period 1983 to 1986 may be related the accummulation of zinc in rainwater as a consequence of the extensive use of zincalome roofing material.

Leaking of metals from the reclaimed tip area is another possible source of heavy metals, as is the sunken ship 'Lake Illawara' buried under a blanket of silt below the Tasman Bridge. To substantiate the contribution of these sources, specific sampling programs would need to be carried out.

Examination of nutrient levels, pesticide concentrations and other water quality criteria have been beyond the scope of this project.

Finally, and of consequence to managements options presented later in this study, Cooper and Langlois (cited in Cooper et al. 1982) when studying heavy metals in sediments and water, observed that Cu and Pb tended to be adsorbed by particulate matter whilst Cd and Zn were mostly in solution. As well, they suggested that sand and sediment have the ability to adsorb soluble heavy metals from sea water when concentrations in sea water are high, but also tend to desorb them slowly to the water as water concentrations fall.

CHAPTER 4

EXAMINATION OF LINDISFARNE BAY SEDIMENTS: DATING BY REDISTRIBUTION OF ^{137}CS, HEAVY METAL CONCENTRATIONS AND GRAINSIZE ANALYSIS

4.1 Introduction

The evaluation of the physical environment (Chapter 3) and the land use history (Chapter 2) of Lindisfarne Bay has indicated that a severe sedimentation problem does exist. This evaluation has highlighted several points namely:

(a) the bay has a shape in a semi-bottleneck and has little current movement. Large sediment deposits forming mudflats are evident at the head of the bay during low tides;

(b) the catchment contains highly erodible soils on moderately steep slopes (Davies 1987), and extensive burning of the understorey has taken place since the late 1940s which has exposed the soils to erosion;

(c) a classical salt water wedge exists in the estuary during winter creating conditions for flocculation of marine and coastal sediment deposits;

(d) tidal movement is in the range of 550mm on average and is volumetrically not considered to be significant;

(e) the discharge of wastes from the EZ works and from sewage treatment plants has meant that it is likely sediments will contain significant levels of heavy metals; and

(f) poorly treated sewage discharged to the river has resulted in high bacterial levels in Lindisfarne Bay.

Based on these characteristics, a sampling program was designed to develop an understanding of the rate of sedimentation and the input of major pollutants (heavy metals) in sediments in Lindisfarne Bay. This chapter outlines the methods used and results obtained in this investigation. Before discussing these aspects however, a brief overview of sedimentation studies using radionuclides in areas polluted with heavy metals is outlined.

Reports on the pollution history of estuaries and other coastal areas are usually based on either combined pollution trace metal and radionuclide analysis or on independent estimates of pollution input and sediment loads (Santschi et al. 1984). The former approach, which has been adopted in this study, can be complicated by difficulties in interpreting the sedimentary records of an environment as dynamic as an estuary or coastal embayment, since postdepositional mixing of particles by physical and biological (bioturbation) mechanisms could alter the original input.

A number of studies have been carried out on heavy metal accumulation in dated sediments. Christensen & Scherfig (1978) for instance, evaluated the historical metal pollution of an estuary in which the primary pollution source was non-point (ie agricultural and urban run-off) and in dating sediment cores, focussed attention on whether the ^{210}Pb technique could be extended to a shallow (0-1.5m) rapidly depositing estuary in which tidal variations were appreciable. To find supportive dating evidence for the determination of sedimentation rates by ^{210}Pb dating, Christensen & Scherfig (1978) examined long-term oscillations in rainfall, grainsize variations versus depth, and concentrations of metals in sediment cores and 'estimated a settleable solids budget.' A sedimentation rate was thus able to be determined by using three independent methods.

In Norway, several studies of heavy metal enrichment in sediment cores from fjords have been carried out (Skei & Paus 1979, Skei 1983, and Naes & Skei 1986). In northern Norway heavy metal analysis, ignition loss and ^{210}Pb dating techniques were utilised in a study on a core from Ranafjord (Skei & Paus 1979). A separate study on a fjord in southern Norway was able to estimate the rate of sedimentation by using historical records, sediment traps and ^{210}Pb dating (Skei 1983). These and other studies (Santschi et al. 1984), have used the ^{210}Pb technique to date sediments in estuaries.

The use of ^{137}Cs in dating sediment accumulation rates has mostly been confined to studies on impoundments of flood plains or as an erosion indicator (McHenry & Ritchie 1980, Brown et al. 1981, Kachanoski & de Jong 1984, McHenry & McIntyre 1984, Campbell et al.1986b, Loughran et al. 1987). In lakes, marshes, and estuaries ^{137}Cs can provide a chronology of the undisturbed sediments or at least a depth of post-1954 deposited sediment (Pennington et al. 1976, Delaune et al. 1978, Ashley & Moritz 1979).

In Chapter 1, an outline of the routing of ^{137}Cs was given and mention made of variations in fallout over time. The temporal pattern in Australia has been shown to have the following principal features (Loughran et al. 1988):

(a) the first appearance of significant amounts of ^{137}Cs in 1954/55 and rapidly increasing in concentration;
(b) a marked decrease in the rate of deposition from 1959 until 1962;
(c) maximum fallout in 1963/64; and
(d) perturbations due to Chinese and French atmospheric tests continuing until the early 1980s.
(Loughran et al. 1988)

The consistent appearance of these features in various studies has enabled interpretation of the sedimentary record to be carried out.

The physio-chemical mobility of sediments is said to be rather insignificant (Duursma 1972 cited in Kacieszczenko & Banasik 1981), however it was felt that the influence of bioturbation on sediments, especially due to the ubiquitous nature of ^{137}Cs in coastal sediment profiles, should be taken into account. Thus using a model, investigations to assess whether the key marking points could be dislocated by bioturbation were carried out by Kacieszczenko & Banasik (1981). Results of this study showed that estuaries with high accumulation rates are little affected by bioturbation. The technique is questionable for sediments accumulating at slow rates (less than one cm per year) but applicable for sediments accumulating at a fast rate (Sharma et al. 1987).

Therefore it is hypothesised that Lindisfarne Bay, due to its apparent rapid rate of sedimentation and estuarine nature, would be suitable to having sediment dated by using the radionuclide ^{137}Cs. To complement the dating program, and uncover the extent of heavy metal accumulation in the sediments, analysis for cadmium, copper, lead and zinc was undertaken.

Innumerable studies have also been conducted on heavy metal enrichment of river sediments due to human-made influences (Forstner & Wittmann 1981). These investigations cover a wide range of regional peculiarities and indicate municipal, industrial and agricultural influences over a wide spectrum of pollution intensities. In Australia, several studies have been carried out near lead or zinc smelters (Bloom 1975, Bloom & Ayling 1977, Ward et al. 1986, Batley 1987). Batley (1987) examined the distribution and bioavailability of heavy metals in water and sediments from Lake Macquarie, New South Wales and attributed their source to the nearby Pb-Zn smelter. Ward et al. (1986) studied the distribution of heavy metals among marine sediments, seagrass, fauna and selected 'sentinel accumulators' resulting from dispersion of wastes from the world's largest lead smelter at Port Pirie in South Australia. In Tasmania, the work of Bloom (1975), and Bloom & Ayling (1977), as mentioned previously, has been the most comprehensive study to date on heavy metal pollution of the Derwent Estuary. They carried out analyses for the presence and concentration of the metals Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni and Zn in filtered water, suspended particulates, sediments, shellfish, fish, airborne particulates and sewage. These Australian studies are mentioned to put this work in a national context.

A third and as mentioned in section 1.4, 'classical' approach to examining sedimentation involves the adoption of a program to sample grainsize, grainshape and mineral components. It was beyond the scope of this work to examine grain shape and mineral component, however grainsize was carried out separately and as part of the ^{137}Cs technique. Thus the three parameters involved in the sampling program were ^{137}Cs activity, heavy metal concentrations, and grainsizes in sediments obtained from core samples.

4.2 Sampling materials and locations

4.2.1 Bay samples

As the physical nature of estuaries varies, so techniques for sampling of sediment must also vary. In many coastal plain-type estuaries extensive areas of low-relief tidal flats may be covered with shallow water for part of the tidal cycle. These may be sampled from a boat or directly by hand at low tide. Strong currents may make the use of grabs or corers, the two principal groups of apparatus available for sampling bottom sediments, impossible to use (Dyer 1979).

In Lindisfarne Bay information was sought with respect to vertical changes in the sediment beneath the surface, hence a grab sampler could not be used because it obtained material from the surface only.

In order to determine the depth of sediment in the intertidal zone of Lindisfarne Bay, which would influence the choice of sampling device, hand auger samples were taken at various locations in the bay. These initial investigatory samples showed that up to 2.5m of sediment was evident in the bay at the tidal interface. As well, the sediments at different locations within the bay had different physical characteristics. For example, sediments from the southeast corner of the head of the bay consisted mainly of a muddy silt (Plate 4.1). The sediment surface at these sites was eutrophic and was difficult to walk over without sinking to knee depth. Conversely, the area in the centre of the eastern head of the bay had a solid surface enabling easy access during low tide (Fig. 4.1, Plate 4.2).

Visual examination of the initial auger samples showed that the sediments contained particles of various sizes, ranging from 50 mm diameter stones to silts and clays. Shell fragments were present at the bottom of the sediment profile at a depth of about 2.5 m.

Different types of corers are available for different uses. Piston corers, such as the Kullenberg corer, are available for deep sea surveying (Dyer 1979) and gravity corers can be used to obtain cores of up to 0.5 m in length in sand. The simplest gravity corers function by free falling through water to penetrate the bed. These corers consist of a metal tube with attached weights and stabilising fins at their upper end. The gravity corer was not suitable for Lindisfarne Bay because it obtained material to a depth of 0.5m only and is essentially designed for underwater sampling.

An adaptation of a gravity corer, used by Mr A Goede of the Geography Department at the University of Tasmania to sample off-shore sands, was used as a model to design a purpose-built coring device to suit Lindisfarne Bay. The coring device, described fully in Appendix B, has two prototypes, namely a 100 mm diameter 1.5m long version and a 50 mm diameter 2.5m long version, each for particular purposes as discussed below. Having designed and constructed a suitable coring device, a number of sampling sites were selected in the intertidal zone of the head of the bay. This area was chosen because it appeared to contain the largest amount of sediment deposition.

Coring (Plate 4.3) was carried out at eight locations between High Water Mark (HWM) and Low Water Mark (LWM) shown in Fig. 4.1. All were well exposed at extreme low tide and in areas where there had been obvious deposition of sediments. Six sets of samples at sites K, L, M, N, O and Q, were collected along a transect (Plate 4.4). The transect was chosen to easily identify the sample locations and because it was an area which appeared to represent the most sediment deposition as indicated by Plates 4.2 and Fig. 4.1. Sites K, L, M and N were 35, 30, 25 and 20 m respectively from the eastern foreshore of the bay and sites O and Q were 40m and 30m respectively from the western foreshore of the bay. Two other sets of samples from sites R and S, were collected from around the head of the bay where sediment deposition had also accumulated (Plates 4.5, 4.6). Site R was located 35 m from the western shore of the bay, about 30m farther out from the transect and three m south of a double storm water drain (Fig. 4.1). Site S was located 18m from the northern edge of the bay opposite Milford Street and two m east of a storm water drain (Fig. 4.1).

Four other sampling sites (D, F, H, and I) were chosen. Sites D and F, were located within half a metre of each other, approximately three metres southwest of site L. Sites H and I were located within half a metre of each other and approximately five m southwest of sites Q.

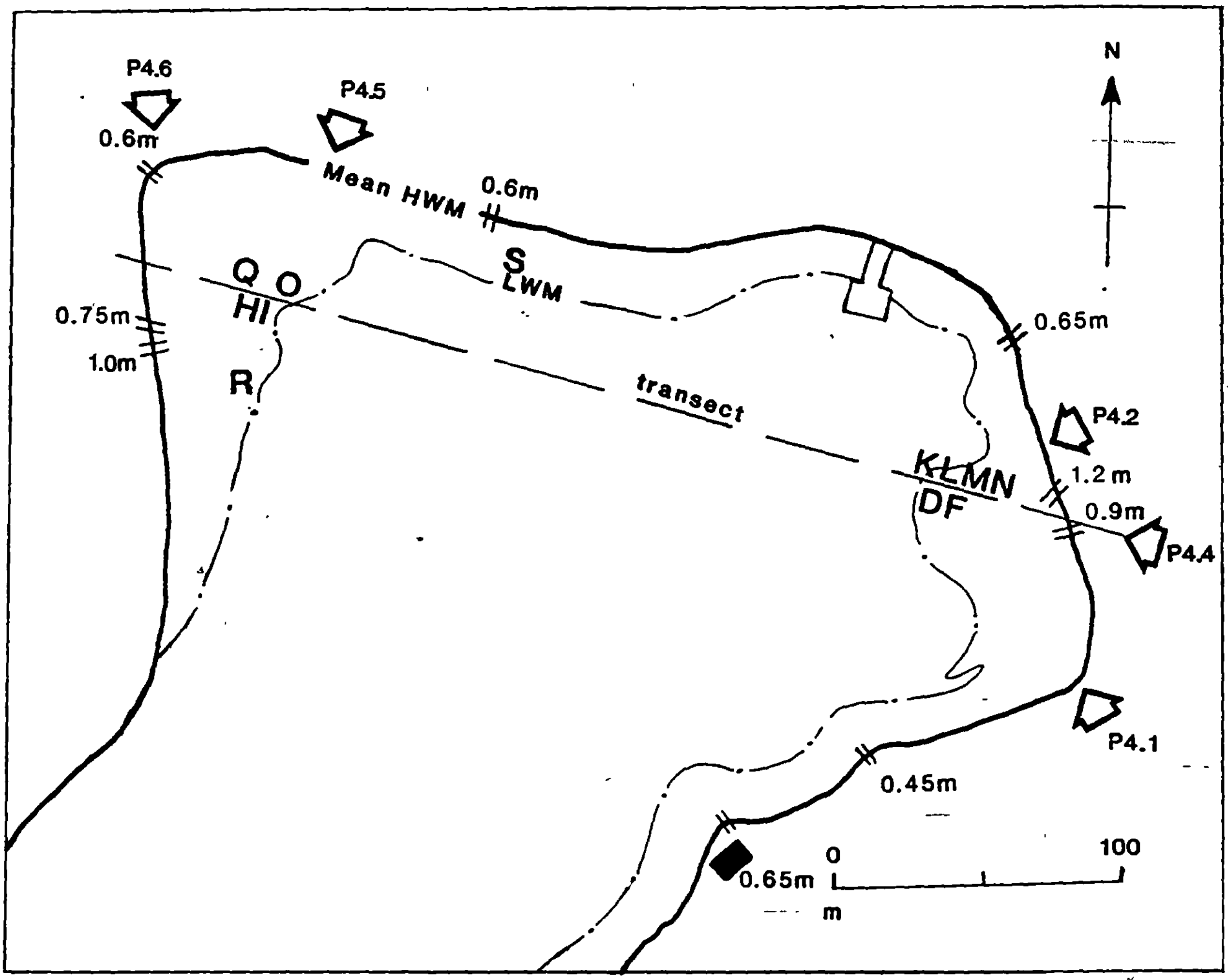
For ^{137}Cs analysis, three core samples each were taken (Plate 4.7) from sites K, L, M, N, O, Q, R and S using the 90mm diameter 1.5m long corer.

Plate 4.1Eastern shore of head of the bay from southeast corner, 1987
Photo taken from location shown in Fig 4.1 (P4.1) during extreme low tide; note the eutrophic nature of the sediment

photo : author

Plate 4.2 Centre of eastern head of the bay looking southwest 1987
Photo taken from location shown in Fig 4.1 (P4.2) during extreme low tide

photo : author



coring site	distance from foreshore (m)
K	35
L	30
M	25
N	20
O	40
Q	30
R	35
S	18
DF	30
HI	30

Fig. 4.1 Sampling sites of the bay

Mean HWM refers to the Mean high water mark while LWM refers to the low water mark; stormwater pipes entering the bay are shown labelled with their diameter; sampling-sites K, L, M, N, O and Q occur on a transect shown and together with site R and S were chosen for obtaining samples for ^{137}Cs analysis; site R was just south of two stormwater pipes; site S was two m east of a stormwater pipe; sites D & F, three m southwest of site L, and site H & I five m southwest of site Q, were chosen for detailed grainsize analysis; all sites had heavy metal analysis performed;

map : this study 1988

Plate 4.3 Coring device

90 mm in diameter & 1.5m long, this UPVC corer was fitted with an adjustable handle and testing plug for effective removal of material; it obtained undisturbed samples to1.4m depth; the corer has been fully described in Appendix B

photo : author

Plate 4.4 Centre of eastern head of the bay showing transect used for core sampling, 1987

Photograph taken from location shown in Fig. 4.1 (P4.4); note that the corer is just visible at the tidal interface at site L

photo : author

Plate 4.5 Northern shore of bay looking south, 1987

Photo taken from location shown in Fig. 4.1 (P4.5) during extreme low tide;

photo : author

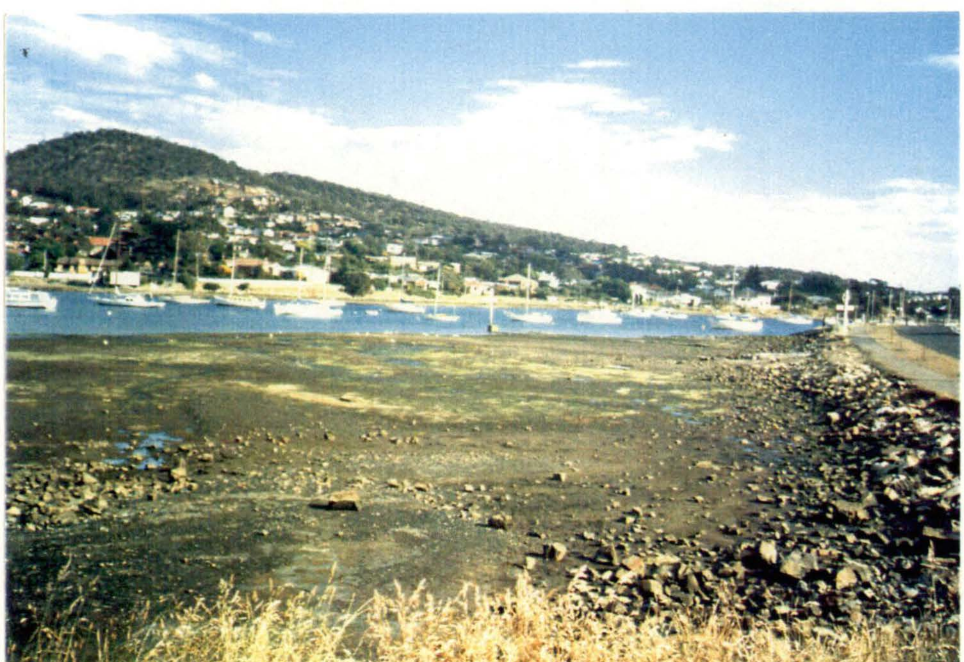


Plate 4.6 Western shore of head of the bay from northwest corner, 1987

Photo taken from location shown in Fig. 4.1 (P4.6) during extreme low tide;

photo : author

Each of the three cores from each site were divided into 100mm long sections and these sections were bulked together (Plate 4.8). This size increment was chosen in order to obtain the desired one kilogram sample size for analysis and to model similar increments in previous research (McCallan et al. 1980, Campbell et al. 1982). Depths of up to 1.5m only were taken because having established that there was a total depth of <2.5m in the intertidal zone, and assuming a steady state of sediment deposition since the onset of colonisation, it was thought that depths of not greater than 1.5m would locate the first appearance of significant quantities of 137Cs, established as 1954. Also to obtain samples to a depth of >1.5m, some form of mechanical assistance would have been required to remove the corer.

For grainsize analysis, the 50mm diameter 2.5m long corer was used so that material could be extracted from the total depth of sediment. One core sample was taken from each of sites D, G, H and I.

Cores from sites labelled K, L, M, N, O, D, F, H, and I, and from Pilchers Hill were taken in March 1987 while sites Q, R and S and from the other catchment sites, discussed below, were taken in November 1987. Sampling times in the bay were dictated by monthly extreme low tides, of approximately 0.5m above Chart Datum Level in accordance with those predicted by the Marine Board of Hobart.

A complete summary of sampling details including site locations, depth of sampling, number of samples and types of analysis carried out is given in Table 4.1. Sites D, F, H, I, K, L, M ,N, O, P, R and S are all located in the intertidal zone. The remainder of the samples come from the catchment.

Plate 4.7 Batches of core samples

Each coring site had three core samples taken and removed for bulking togther for ^{137}Cs analysis

photo : author

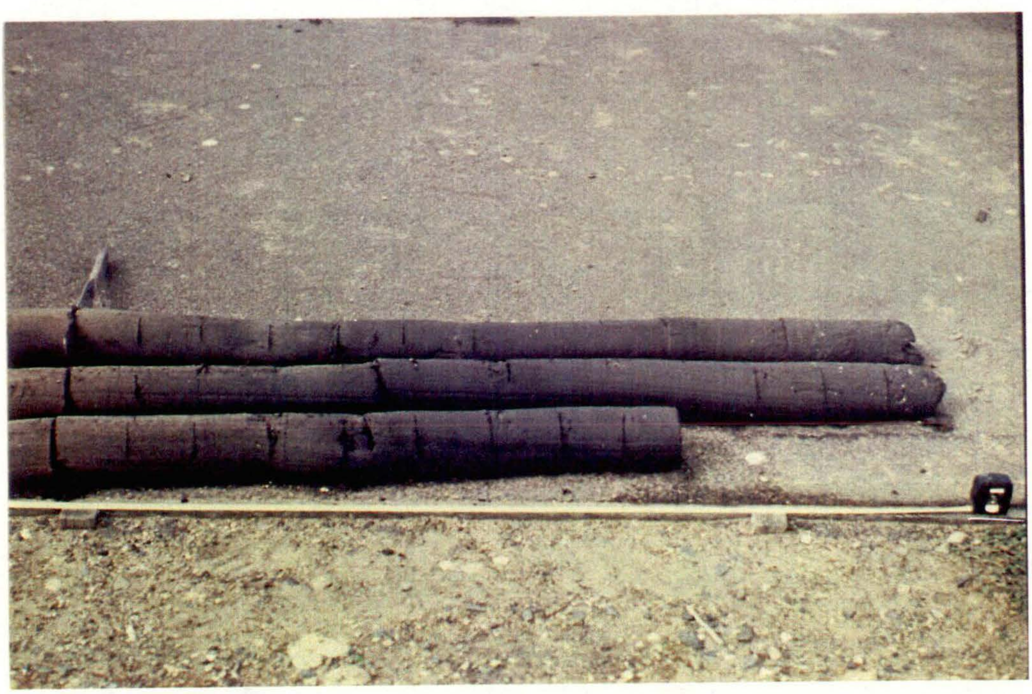


Plate 4.8 Core samples showing 100mm sectioning

Each of the cores were cut into 100 mm sections and bulked together so as to obtain the desired one kilogram sample size of particles < 2mm necessary for 137Cs analysis

photo : author

TABLE 4.1: Sample details (to be read in conjunction with Fig 4.1 & text)

Site	*Location*	*Depth*	*Samples per core*	*Analysis performed*	*Size of corer* (length x dia.)
D	east end of bay	2.5m	6	grain size	2.5 x .05m
F	east end of bay	2.4m	6	grain size	2.5 x .05m
H	west end of bay	2.3m	6	grain size	2.5 x .05m
I	west end of bay	2.5m	6	grain size	2.5 x .05m
K	transect 30m east	1.3m	11	^{137}Cs, metals, pesticides	1.5 x 0.09m
L	transect 25m east	1.4m	13	^{137}Cs, metals, pesticides	1.5 x 0.09m
M	transect 20m east	1.4m	12	^{137}Cs, metals, pesticides	1.5 x 0.09m
N	transect 15m east	1.1m	10	^{137}Cs, metals, pesticides	1.5 x 0.09m
O	transect 40m west	1.2m	12	^{137}Cs, metals, pesticides	1.5 x 0.09m
Q	transect 30m west	1.3m	12	^{137}Cs, metals	1.5 x 0.09m
R	30m from west	0.65m	7	^{137}Cs, metals	1.5 x 0.09m
S	18m from north	1.0m	7	^{137}Cs, metals	1.5 x 0.09m
V1	Natone Hill	160 mm	1	^{137}Cs	0.3 x 0.1m
V2	Natone Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
V3	Natone Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
V4	Natone Hill	125 mm	1	^{137}Cs	0.3 x 0.1m
V5	Natone Hill	115 mm	1	^{137}Cs	0.3 x 0.1m
V6	Natone Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
W1	Gordons Hill	150 mm	1	^{137}Cs	0.3 x 0.1m
W2	Gordons Hill	160 mm	1	^{137}Cs	0.3 x 0.1m
W3	Gordons Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
W4	Gordons Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
W5	Gordons Hill	160 mm	1	^{137}Cs	0.3 x 0.1m
W6	Gordons Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
Y	Pilchers Hill	120 mm	7	^{137}Cs	cradle
Z1	Pilchers Hill	200 mm	1	^{137}Cs	0.3 x 0.1m
Z2	Pilchers Hill	200 mm	1	^{137}Cs	0.3 x 0.1m

4.2.2 Catchment samples

Core samples from Natone Hill, Gordons Hill and Pilchers Hill (Plates 3.1, 3.2 & Fig 4.2) were taken to depths of up to 200mm using a 300mm long, 100 mm diameter stainless steel cylinder. The sampling method used involved hammering the stainless steel cyclinder, fitted with a solid steel lid for that purpose, into the earth. The surrounding earth was then dug away so that the coring device containing the 200 mm long core could be removed intact. A typical sample is shown in Plate 4.9. Also samples were taken from Pilchers Hill using a cradle (Plate 4.10). The following is a discussion of catchment sampling sites.

Natone Hill showed evidence of active erosion and samples were therefore taken from six sites down the southeastern slope of the hill draining directly into Lindisfarne Bay. These are represented by sample numbers V1, V2, V3, V4, V5, and V6 and are shown in Fig 4.2.

Site V1 was on the crest of the slope between the summit of Natone Hill and the reservoir and approximately 60 m from the reservoir. The site showed signs of having been burnt within the previous 12 months and was partially cleared. Although there was little grass cover, an open canopy of Casuarina stricta and Eucalyptus sp. was present. The soil was sampled to a depth of 160 mm.

Site V2 was located about 80 m down the slope from V1 on the up-hill side of a four wheel drive track. It was on a slope of about one in four (1 in 4) and showed evidence of microterracing. The site had also been recently burnt and had little or no vegetative cover at ground level.

Site V3 was located at the same altitude as V2 and approximately 30 m to its east. Vegetative ground cover had been removed by fire but an open canopy of Casuarina stricta remained. The site showed no microterracing and was chosen to allow comparison with site V2. The soil was sampled to a depth of 50mm.

Site V4 was a further 100 m down the slope on a grade of 1 in 3. Native grasses and weeds were present. The soil at this site was sampled to a depth of 125 mm which included 80 - 85 mm B horizon soil.

Site V5 was located a further 10 m down the slope in a small gully approximately 50 cm wide and 30 cm deep. The site generally appeared to be similar to site V4 except that there was no vegetative cover in the vicinity of the core site. The A horizon was absent, and the B horizon was sampled to a depth of approximately 115 mm.

Plate 4.9 Typical catchment sample obtained for ^{137}Cs analysis

photo : author

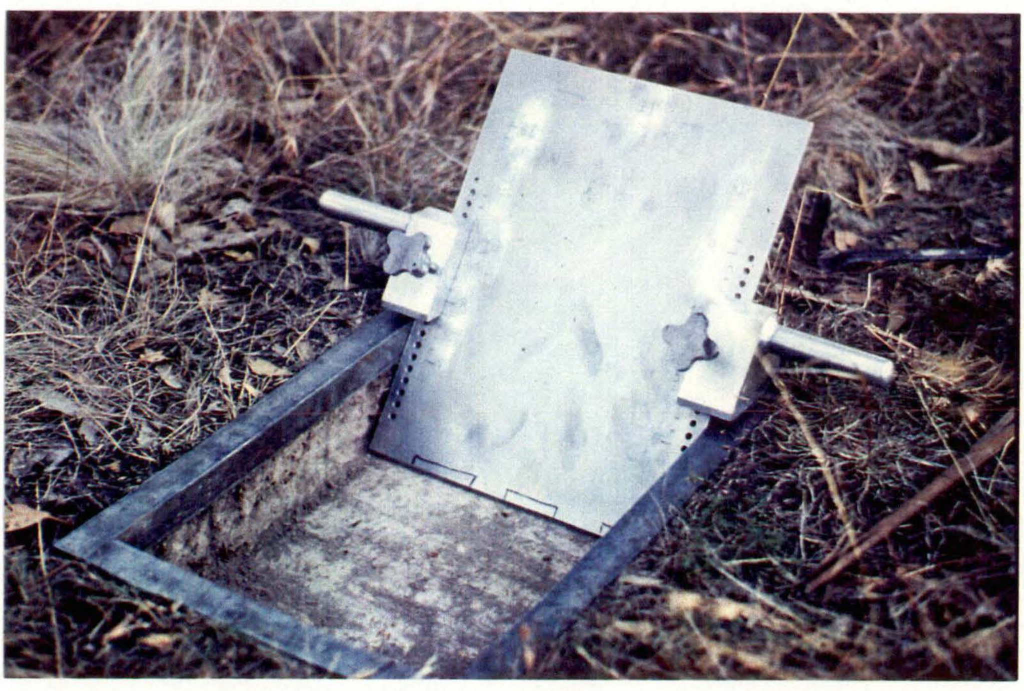


Plate 4.10 Sample cradle used on Pilchers Hill

The sample cradle removed material over the area of the frame at adjustable depths; cradle designed and built by ANSTO

photo : author

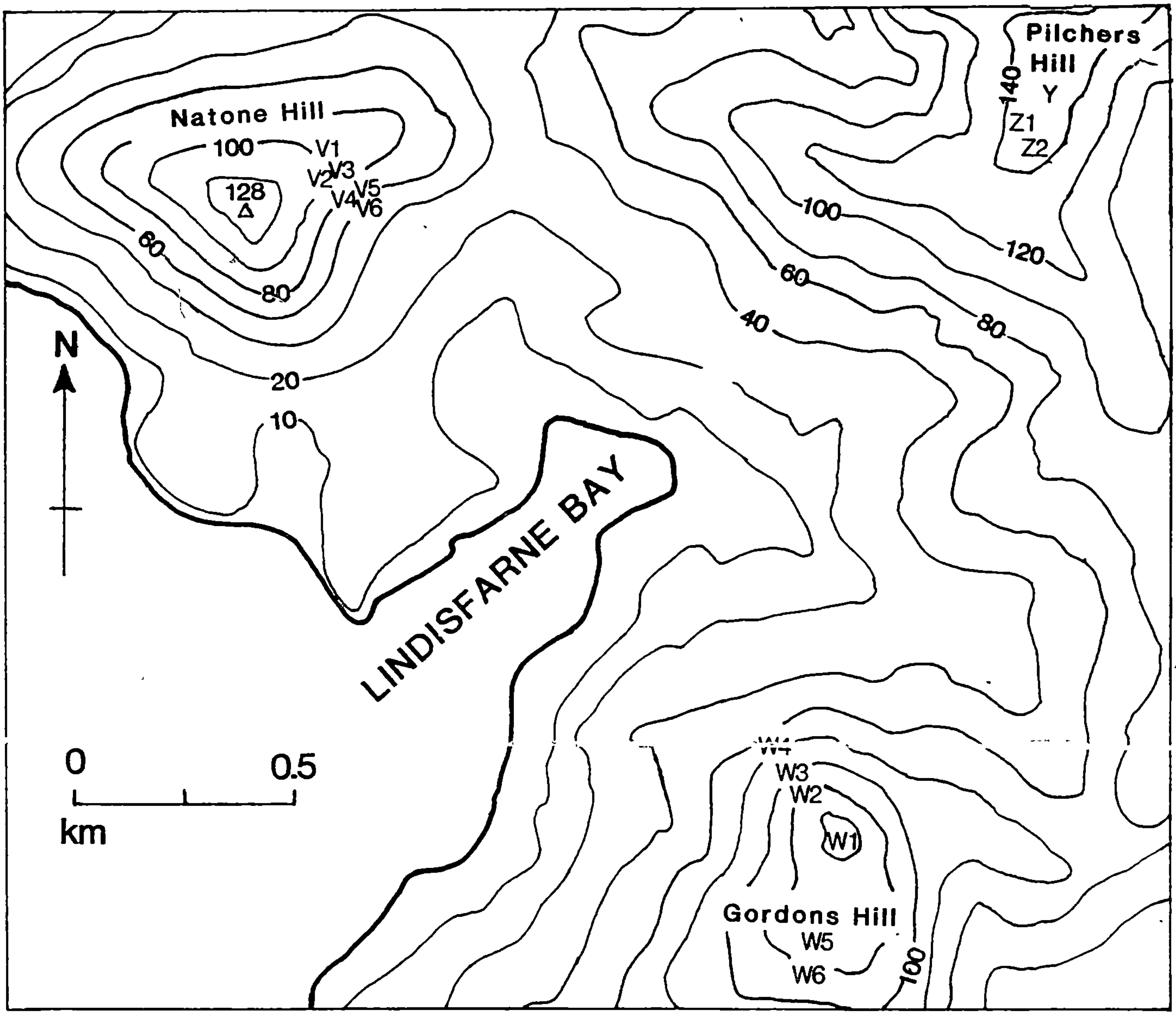


Fig. 4.2 Sampling sites of the catchment

Sites on Natone Hill V1, V2, V3, V4, V5 and V6, on Gordons Hill W1, W2, W3, W4, W5 and W6, and on Pilchers Hill Z1 and Z2 were sampled with a 100 mm cyclinder; site Y was sampled incremently with a cradle shown in Plate 4.10; sites Z1 and Z2 together with site Y were sampled to determine input values for the region

source : Lands Dept. Tasmania, 1985, 1:25000 series Hobart

Site V6 was located on the lower slope a further 30 metres from V5, on a site of soil deposition defined visually and having a reasonable grass cover with a canopy of Casuarina stricta. The A_2/B soil horizon transition was found at approximately 100 mm, and soil at this site was sampled to a depth of approximately 200 mm.

Gordons Hill is located on the south of the bay in the Gordons Hill State Recreation Area. A fitness track circumnavigates the southern edge of the hill on approximately the 75 m contour. Four sampling sites were selected on the northwestern slope of Gordons Hill, commencing from the summit and progressing down the slope. Two more sites were selected on the southern slope (Fig. 4.2).

Site W1 was located on flat ground near the summit. The vegetation was predominantly Casuarina stricta with a good cover of native grasses.

Site W2 was located 70 m northwest of the summit on a slope of grade 1 in 3 under a tree canopy of Casuarina stricta and amid dolerite outcrops. The grass showed evidence of having been burnt recently. Soil at this site was sampled to a depth of 160 mm.

Site W3 was located a further 30 m from site W2 and had a similiar vegetative cover to site W2 except it was in the midst of more dolerite outcrops. The sample at this site was taken from the edge of an embankment to a depth of 200 mm.

Site W4 was located towards the lower slope in long native grass 50 m from W3 and approximately 120 m from urban development. Tree cover consisted of Eucalyptus sp., Acacia sp. and Casuarina stricta. Soil at this site was sampled to a depth of 200 mm.

Sites W5 and W6 were located on the southern side of Gordons Hill approximately half way down the slope. From the appearance of mature Casuarina stricta around the area the site appeared relatively stable. Soils at these sites were sampled to bedrock depth (160mm for W5 and 200mm for W6).

The Pilchers Hill sampling site was located in open grass woodland with a canopy of eucalypts on a gentle slope (Fig. 4.2). This site was selected for sampling to obtain an inventory of ^{137}Cs input for the region. It has been reported that the choice of sites for input sampling is critical (Loughran et al. 1988). Open sites on hilltops, undisturbed by animal or human activity, are preferred. Forested hilltops, although probably stable, may have been labelled unevenly due to the variable effects of canopy cover, wind funelling, leaf drip, stemflow etc. (Loughran et al. 1988).

The input value of ^{137}Cs for the catchment, which acts as a reference value, must be estimated in order to study the redistribution of ^{137}Cs at any site (Longmore et al. 1983). The reference value is defined as the total ^{137}Cs fallout, in terms of areal concentration for the site, corrected for decay to the year of sampling. This may be estimated from fallout data obtained from areal concentrations on adjacent flat hilltops where there is believed to be no erosion or deposition of soil (McCallan et al. 1980). The areal concentration can then be calculated by integrating the vertical activity at the site. The ^{137}Cs content at a given site is calculated by dividing the total ^{137}Cs count (millibecquerels per gram) by the ground surface area of the sampling core or device (cm^2) to give millibecquerels per square centimetre. To obtain these areal activites for the establishment of a reference value, normally at least three sites are sampled in close proximity, one by depth increments and the remainder by coring (Campbell et al. 1982, Loughran et al. 1988).

Consequently depth increment samples from Pilchers Hill were collected by use of a sampling frame (Plate 4.10), across its area at depths of 0-10 mm, 10-20 mm, 20-40 mm, 40-60 mm, 60-80 mm, 80-100 mm and 100-120 mm. Two further samples were taken using a 300 mm stainless steel corer (Z1 & Z2) so that together with incremented site samples an average areal activity for the region, unknown prior to this work, could be obtained.

All sample was bagged and labelled for transportation to the laboratory for processing and analysis.

4.3 Dating by redistribution of ^{137}Cs

4.3.1 Methods

After oven drying at 105°C for 12 hours and disaggregation by a mortar and pestle, each sample was passed through a two mm sieve. The fraction greater than two mm was put aside and the remaining sieved fraction (<2mm) mixed to give a constant density and a constant radioactive counting geometry and then subsampled to approximately one kilogram. Samples were bagged, labelled and transported to the Australian Nuclear Science and Technology Organisation (ANSTO) laboratories. At ANSTO the samples were analysed for determination of ^{137}Cs content. ^{137}Cs has a half life of 30 years and because it possesses an energetic gamma emission, measurement can be taken directly from soil.

Caesium 137 was determined by gamma ray spectoscopy using a hyperpure germanium semiconductor detector to measure the 662 keV gamma ray emitted by it. A stable low noise amplifier (Canberra 1416B / 1413) was used with the detector together with a multi-channel analyser (Nuclear Data Series 2200). The detector, vertically mounted in a Dewar and with its end protruding into approximately 90 mm of a thick lead cell was supported by five mm of steel sheet on a steel stand. Note that the lead and steel were of low background material, being 100 and 200 years old respectively.

Gamma radiation from ^{137}Cs present in the samples was measured in units of millibecquerels per gram (mBq/gm) of dry sediment.

It has been reported (Tamura 1964, McHenry et al. 1973) that ^{137}Cs is known to have an affinity for clay as well as for organic colloids within the soil. Since ^{137}Cs is adsorbed preferentially in the finer sediments, the ^{137}Cs technique can be further refined by expressing the concentration of ^{137}Cs per gram of silt and clay in the sample (Campbell et al. 1982). However, concentrations can also be expressed as areal activities using the amount of material less than two mm.

In this study, silt and clay, sand, and gravel fractions have all been determined and assist in understanding sedimentological features. The silt and clay fraction was calculated according to the USDA and International standard and determined by hydrometer method (Smith & Atkinson 1975). Organic content of each sample, calculated by ashing at 400°C, was determined prior to hydrometer analysis. Samples with organic contents greater than eight percent, as determined by ignition (Krumbein & Pettijohn 1938), were treated with hydrogen peroxide by methods outlined by Bouyoucos (1926). The Bouyoucos hydrometer technique applied in this study utilised three clay & silt limits namely:

(a) 40 seconds (United States Department of Agriculture [USDA] limit for percent silt & clay);
(b) four minutes (International limit for percent silt & clay); and
(c) two hours (the USDA and International limit for percent clay).

The latter limit was used because of its more universal acceptance. During calculations by hydrometer methods for silt & clay counts, several corrections were necessary. A meniscus correction was determined to be one mg/l, so all results were corrected by the addition of a factor of one. As the hydrometer was calibrated for a suspension of 20°C, it was necessary to correct for temperature variation by the addition or subtraction respectively of 0.3 units per degree above or below 20°C. Another correction was for that of the density of calgon by the subtraction of 0.5 units for each 10 ml added to the suspension. Thus as 10 mls of calgon was added to each sample, 0.5 units was subtracted from each result obtained.

The gravel fraction (particles greater than two mm) was determined by dry sieving. Having obtained the fraction less than two mm, and knowing the surface area of the cored material, the areal activity, or concentration per unit of ground surface area (mBqcm-2) was calculated using ther following formula:

$$\frac{\text{sample weight (<2mm)g.} \quad \times \quad {}^{137}\text{Cs concentration <2mm of sample (mBq/g)}}{\text{area of corer or cylinder or sampling frame (cm2)}} = {}^{137}\text{Cs (areal act.)mBq cm}^{-2}$$

This determination assumes no ^{137}Cs on fraction >2mm.

4.3.2 Dating by redistribution of ^{137}Cs : results

Results of ^{137}Cs analyses for core samples taken in Lindisfarne Bay are given in Table 4.2. The first column shows depth increments for each sample. Organic content shown as a percentage by weight are given in the second column. Caesium per gram of sample, shown in column three, represents data obtained for the amount of gamma radiation emitted by ^{137}Cs per gram of sample as calculated by ANSTO. Analytic errors which are absolute are included in this column. Values of less than 0.6mBq/gm are not considered significant (Campbell pers comm). Total mass of each sample are shown in the fourth column. Percent silt and clay (gm/l), shown in the fifth column, represents the amount of silt and clay per sample (USDA and International Standard). Percent gravel, as determined by dry sieving through a two mm screen are shown in column six of Table 4.2. The seventh column shows the mass or weight of material less than two mm. The last column shows areal activity expressed as in mBq cm^{-2}. To determine the areal activites, it was necessary to take into account the area of the corer, cylinder or sampling frame.

The inside diameter of the corer used for obtaining Bay samples was nine centimetres and the diameter of the cylinder used for obtaining catchment samples was ten centimetres. Therefore the areas of the corer and cylinder respectively were 63.6 and 78.5 square centimetres.

Table 4.2 Results of ^{137}Cs analysis from core & catchment samples of Lindisfarne Bay

Note : Depths 20-30 cm in core N show ^{137}Cs in total sample = 0.6 mBq/gm which has not been treated as ND due to the error value of 0.6.

1	2	3	4	5	6	7	8
Depth	Organic content	137Cs in <2mm sample	Total weight	Silt & clay content	Gravel content	Sample mass <2m	137Cs areal activity
(cm)	(%)	(mBq/gm)	(gm)	(%)	(%)	(gm)	(mBq/cm2)
CORE L							
0-10	1.5	0.0 ± 0.5	2012	4.7	16.2	1685	ND
10-20	1.4	0.4 ± 0.5	2052	3.3	10.3	1840	ND
20-30	0.9	0.5 ± 0.5	1712	4.8	8.2	1571	ND
30-40	1.8	1.00 ± 0.4	1856	5.0	1.4	1848	29.1 ± 11.6
40-50	2.1	0.80 ± 0.4	1907	4.1	4.1	1828	23.0 ± 11.5
50-60	2.2	1.90 ± 0.6	2003	6.7	1.6	1970	58.9 ± 18.6
60-70	1.4	1.50 ± 0.6	1633	6.0	1.3	1612	38.0 ± 15.2
70-80	2.1	3.10 ± 0.4	1761	7.2	2.8	1712	83.4 ± 10.7
80-90	2.9	3.40 ± 0.3	1964	9.6	3.7	1891	101.1 ± 8.9
90-100	1.7	3.20 ± 0.4	2109	8.8	2.9	2048	103.0 ± 12.9
100-110	0.8	-0.6 ± 0.4	2276	6.2	18.8	1848	ND
110-120	1.2	-0.5 ± 0.4	2065	6.1	22.7	1513	ND
120-140	1.1	-0.6 ± 0.4	1847	4.7	16.1	1549	ND
							436.5
CORE M							
0-10	2.6	0.2 ± 0.5	2212	2.2	5.2	2097	ND
10-20	2.9	1.1 ± 0.5	1940	4.0	10.9	1728	29.9 ± 13.6
20-30	3.7	0.1 ± 0.5	1915	1.4	29.9	1342	ND
30-40	2.3	0.9 ± 0.4	1815	3.3	24.1	1377	19.5 ± 6.0
40-50	1.9	-0.1 ± 0.4	2067	4.1	6.8	1926	ND
50-60	2.1	2.1 ± 0.5	2077	6.7	3.3	1941	64.1 ± 15.2
60-70	1.2	2.3 ± 0.6	2099	7.8	2.6	2044	73.9 ± 19.3
70-80	3.1	1.9 ± 0.4	1966	7.4	2.7	1913	57.1 ± 12.0
80-90	3.3	3.6 ± 0.3	1725	8.1	1.9	1692	95.8 ± 8.0
90-100	2.8	1.9 ± 0.4	1709	4.8	3.8	1644	72.4 ± 10.3
100-120	1.5	0.6 ± 0.4	1791	4.8	4.4	1712	ND
120-140	1.6	-0.3 ± 0.4	1627	4.9	14	1399	ND
							412.7
CORE N							
0-10	3.8	0.1 ± 0.4	1868	1.3	19.3	1695	ND
10-20	4	0.0 ± 0.3	2073	1.3	23.5	1586	ND
20-30	3.2	0.6 ± 0.6	2471	1.6	25.1	1851	17.5 ± 17.5
30-40	2.3	1.0 ± 0.2	1724	1.6	7.2	1600	25.1 ± 5.0
40-50	1.5	1.7 ± 0.2	1811	3.1	0.8	1797	48.0 ± 5.6
50-60	1.6	1.5 ± 0.2	1698	3.1	2.9	1649	38.8 ± 5.2
60-70	2.1	1.2 ± 0.3	1464	3.7	2.5	1428	26.9 ± 6.7
70-80	2.3	1.7 ± 0.4	1726	5.1	3.1	1673	44.7 ± 10.5
80-90	3.8	3.2 ± 0.4	1533	7.5	10.8	1368	68.8 ± 8.6
90-110	3	3.7 ± 0.4	1465	9.5	12.1	1287	100.5 ± 10.8
							370.3

Table 4.2 continued

Depth	Organic	137Cs in	Total	Silt & clay	Gravel	Sample	137Cs
	content	<2mm sample	weight	content	content	mass <2m	areal activity
(cm)	(%)	(mBq/gm)	(gm)	(%)	(%)	(gm)	(mBq/cm2)
CORE K							
0-10	3.1	0.5 ± 0.3	2565	3.3	8.7	2348	ND
10-20	4.7	0.2 ± 0.4	2868	3.7	6.4	2684	ND
20-30	3.9	0.4 ± 0.5	2423	5.4	9.1	2202	ND
30-40	3	1.1 ± 0.5	2385	9.0	3.2	2308	39.9 ± 18.1
40-50	2.5	2.1 ± 0.5	2410	8.0	2.8	2342	77.3 ± 18.4
50-60	2.2	1.5 ± 0.6	2540	9.8	1.6	2499	58.9 ± 23.6
60-70	2.2	2.4 ± 0.6	2487	6.5	1.1	2459	92.8 ± 23.2
70-80	2.7	3.3 ± 0.6	2467	7.4	0.5	2454	127.4 ± 23.1
80-90	1.9	1.8 ± 0.4	2321	7.0	3.7	2235	63.2 ± 14.0
90-110	2.3	-0.2 ± 0.3	2103	4.1	5.6	2027	ND
110-130	1.6	0.0 ± 0.4	1654	3.9	14.8	1409	ND
							459.5
CORE O							
0-10	2.3	1.2 ± 0.4	2564	5.3	15.6	2164	40.8 ± 13.6
10-20	2	0.2 ± 0.3	2478	6.1	28.7	1766	ND
20-30	1.8	0.0	2381	5.9	10.9	2121	ND
30-40	2.3	-0.6 ± 0.5	2617	7.8	6.3	2452	ND
40-50	4.6	-0.1 ± 0.5	2465	8.2	4.8	2346	ND
50-60	1.6	0.0	2471	5.5	2.8	2401	ND
60-70	1.3	-0.1 ± 0.5	2403	5.7	3.9	2309	ND
70-80	1	-0.4 ± 0.4	2489	4.9	3.1	2411	ND
80-90	0.9	-0.3 ± 0.3	2365	2.9	2.8	2298	ND
90-100	1.2	0.6 ± 0.3	2312	2.9	3.5	2231	ND
100-110	1.2	-0.5 ± 0.3	2103	3.0	10.4	1884	ND
110-120	1.5	-0.4 ± 0.4	1868	2.7	13.5	1615	ND
							40.8 ± 13.6
CORE Q							
0-10	1.7	0.9 ± 0.4	2675	4.0	12.1	2351	33.3 ± 14.8
10-20	2.4	ND	2639	4.5	25.3	1972	ND
20-30	5.6	ND	2352	6.5	12.9	2050	ND
30-40	3.9	ND	2669	6.6	13.4	2336	ND
40-50	2.4	ND	2660	4.6	1.2	2652	ND
50-60	1.7	ND	2551	4.6	0.9	2627	ND
60-70	0.9	ND	2565	0.6	2.6	2541	ND
70-80	0.9	ND	2668	0.9	2.8	2592	ND
80-90	0.7	ND	2681	1.2	3.0	2602	ND
90-100	0.9	ND	2745	1.2	4.8	2614	ND
100-110	0.8	ND	2515	14.8	15.9	2116	ND
110-120	1.9	ND	3056	8.7	34.7	1997	ND
							33.3 ± 14.8

Table 4.2 continued

Depth	Organic	137Cs in	Total	Silt & clay	Gravel	Sample	137Cs
	content	<2mm sample	weight	content	content	mass <2m	areal activity
(cm)	(%)	(mBq/gm)	(gm)	(%)	(%)	(gm)	(mBq/cm2)
CORE R							
0-10	2.9	2.7 ± 0.4	1927	6.8	12.7	1683	71.4 ± 10.6
10-20	2.2	3.0 ± 0.5	2558	5.8	27.0	1868	88.1 ± 14.7
20-30	2.3	1.6 ± 0.5	2525	4.8	24.8	1898	47.7 ± 14.9
30-40	3.1	3.1 ± 0.5	2215	6.8	13.8	1909	93.0 ± 15.0
40-50	3.1	3.1 ± 0.3	1817	14.8	3.2	1759	85.7 ± 8.3
50-60	2.4	1.3 ± 0.5	1159	12.8	11.1	1030	21.0 ± 8.1
60-65	2.1	1.5 ± 0.3	1500	15.4	25.5	1155	27.2 ± 5.4
							434.1
CORE S							
0-10	1.2	0.8 ± 0.4	2804	3.0	26.8	2052	25.8 ± 12.9
10-20	1.6	1.3 ± 0.4	2418	4.0	15.8	2036	41.6 ± 12.8
20-30	1	1.6 ± 0.4	2812	2.0	26.9	2056	51.7 ± 12.9
30-40	1.1	1.1 ± 0.5	2783	3.0	28.0	2004	34.6 ± 15.7
40-50	1.5	1.7 ± 0.5	2837	3.4	29.6	1997	53.4 ± 15.7
50-60	2.6	2.2 ± 0.4	2173	5.0	15.1	2062	71.3 ± 12.7
60-70	4	5.5 ± 0.5	1970	9.0	7.1	1829	158.2 ± 14.4
70-80	3.3	3.2 ± 0.3	2395	7.0	2.3	2340	117.7 ± 11.0
80-90	3.5	3.6 ± 0.5	1387	15.0	2.4	1381	78.2 ± 10.8
90-100	4.1	2.1 ± 0.5	800	27.0	29.4	485	16.0 ± 3.8
							648.5
		PILCHERS		HILL			
Z1 (20)	5.4	3.6 ± 0.7	2172	22.0	17.6	1790	82.1 ± 15.9
Z2 (20)	3.5	4.4 ± 0.6	1988	23.5	23.7	1517	85.0 ± 11.6
Y 0-1	9.9	46.7 ± 1.8	1534	14.3	17.9	1259	42.2 ± 1.6
Y 1-2	7.9	21.9 ± 0.9	1459	16.4	24.7	1098	17.3 ± 0.7
Y 2-4	7.8	5.0 ± 0.4	2350	18.3	44.9	1295	4.6 ± 0.4
Y 4-6	7.3	1.7 ± 0.6	2913	21.9	53	1369	1.7 ± 0.6
Y 6-8	7.3	0.1 ± 0.4	3042	25.0	49.6	1534	0.1 ± 0.4
							65.9
		GORDONS		HILL			
W5 (16)	5.9	3.0 ± 0.3	1294	12.9	9.4	1172	44.8 ± 4.5
W6(20)	6.3	3.5 ± 0.3	1370	12.7	9.8	1236	55.1 ± 4.7
W1 (15)	15.4	3.6 ± 0.3	834	6.0	9.2	757	34.7 ± 2.9
W2 (16)	14.8	3.7 ± 0.3	976	6.6	8.0	898	42.3 ± 3.4
W3 (20)	9.9	3.2 ± 0.3	1514	4.8	23.3	1161	47.3 ± 4.4
W4 (20)	0.8	2.5 ± 0.4	1493	8.0	18.7	1197	38.1 ± 6.1
		NATONE		HILL			
V1 (16)	5.6	3.2 ± 0.4	1352	10.0	33.5	899	36.6 ± 4.6
V2 (20)	2.8	4.7 ± 0.4	854	16.7	36.5	542	32.4 ± 2.7
V3 (20)	6.7	13.4 ± 0.5	1658	17.0	37.6	1034	176.5 ± 6.6
V4 (12.5	8.4	9.6 ± 0.4	1223	25.8	50.0	611	74.7 ± 3.1
V5 (11.5	3.1	1.7 ± 0.4	1179	24.6	21.5	928	20.0 ± 4.7
V6 (20)	7.4	4.4 ± 0.5	1761	23.6	22.9	1354	75.9 ± 8.6

The dimensions of the sampling frame used on Pilchers Hill to determine incremented reference values, was 457mm x 305mm resulting in an area of 1393.85 cm^2.

Having refined the data to this level, a graphical presentation of the areal activities for each core has been provided showing depth (m) versus amount of ^{137}Cs (mBq cm^{-2}) (Fig 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10). The lines above the histograms represent error bars which are absolute while the dotted line shows the depth of coring.

Reference values for the region were determined from areal activity of samples taken from stable sites on Pilchers Hill (Plate 3.3). Three references sites were sampled (Fig. 4.2, Table 4.2), one by depth increments to eight cm (site Y) and two by coring to 200 mm. Ninety percent or 59.5 mBq cm^{-2} of the ^{137}Cs activity was present in the top two cm of the profile in the sample obtained by depth increment. The total ^{137}Cs activity in eight cm of soil was 65.9 mBq cm^{-2}. The cored sites showed activities of 82.1 ± 15.9 and 85.0 ± 11.6 mBq cm^{-2} respectively, resulting in an average reference value for the region of 77.6mBq cm^{-2}.

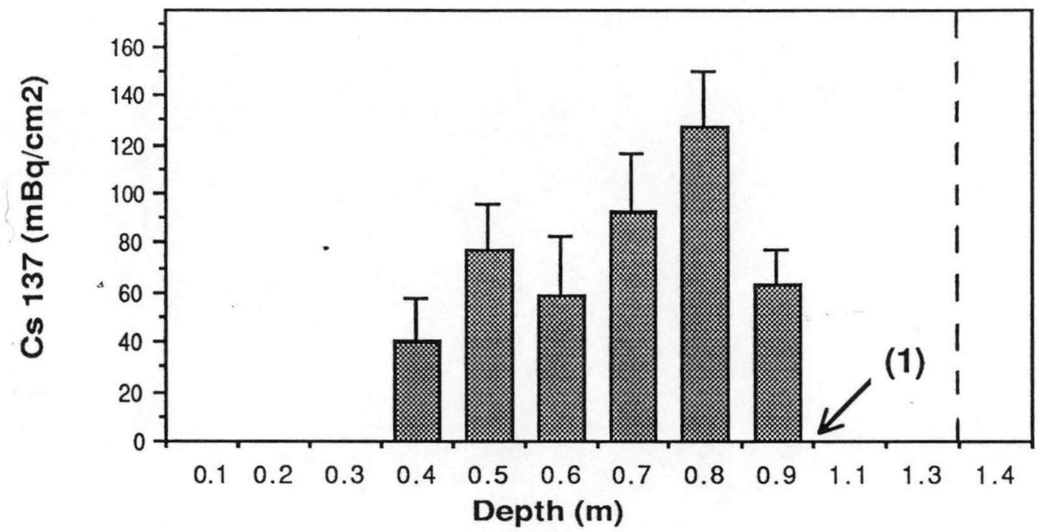


Fig. 4.3 Core K : areal activity vs depth

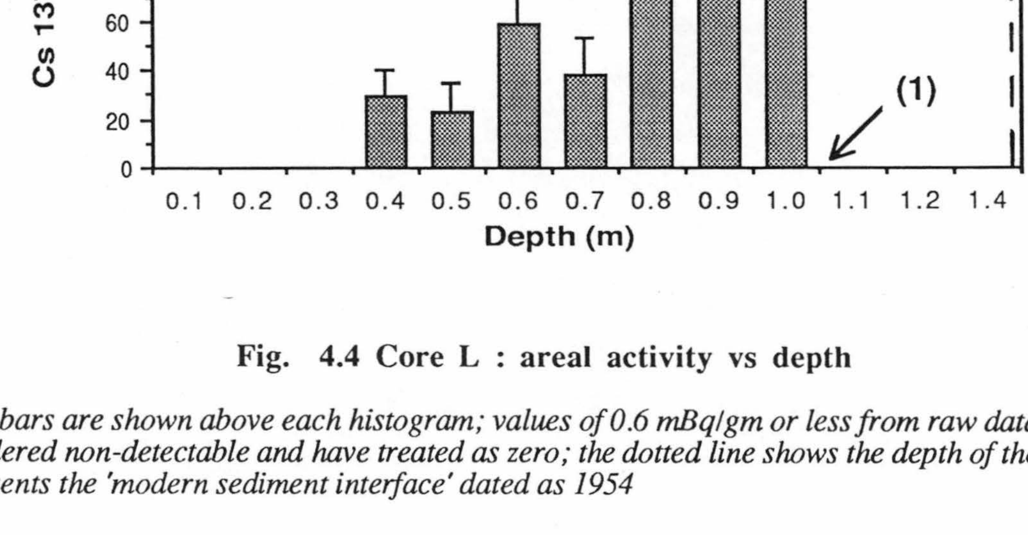


Fig. 4.4 Core L : areal activity vs depth

Error bars are shown above each histogram; values of 0.6 mBq/gm or less from raw data are considered non-detectable and have treated as zero; the dotted line shows the depth of the core; (1) represents the 'modern sediment interface' dated as 1954

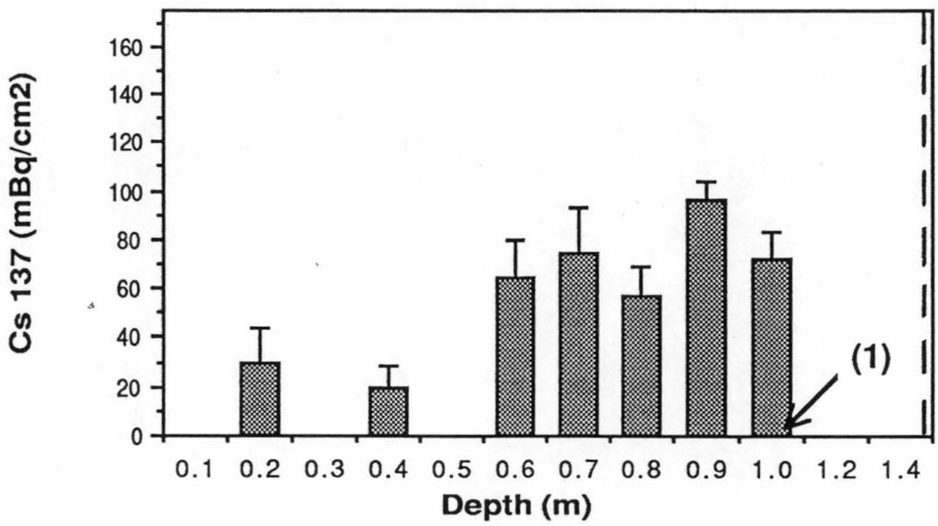


Fig. 4.5 Core M : areal activity vs depth

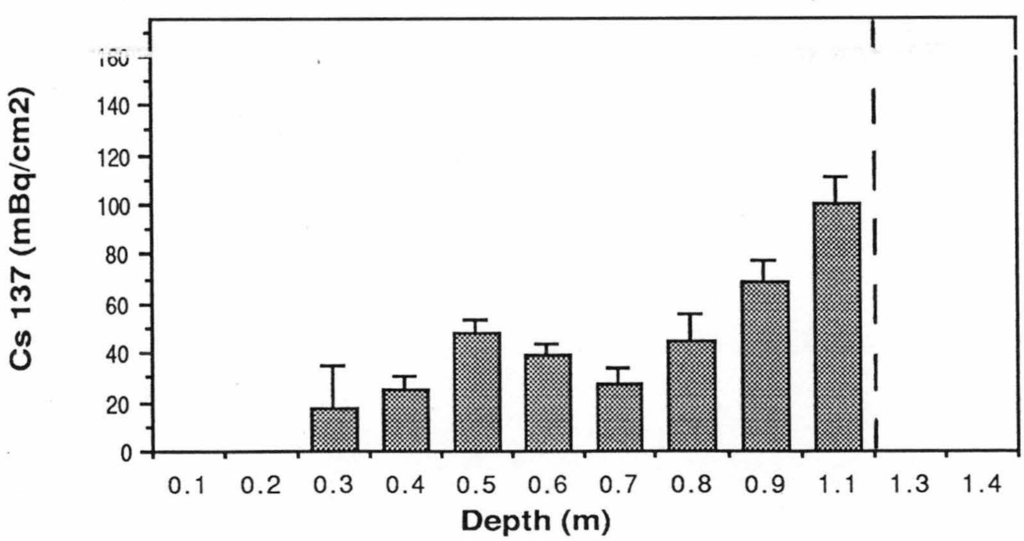


Fig. 4.6 Core N : areal activity vs depth

Error bars are shown above each histogram; values of 0.6 mBq/gm or less are considered non-detectable and have treated as zero; the dotted line shows the depth of the core; (1) represents the 'modern sediment interface' dated as 1954

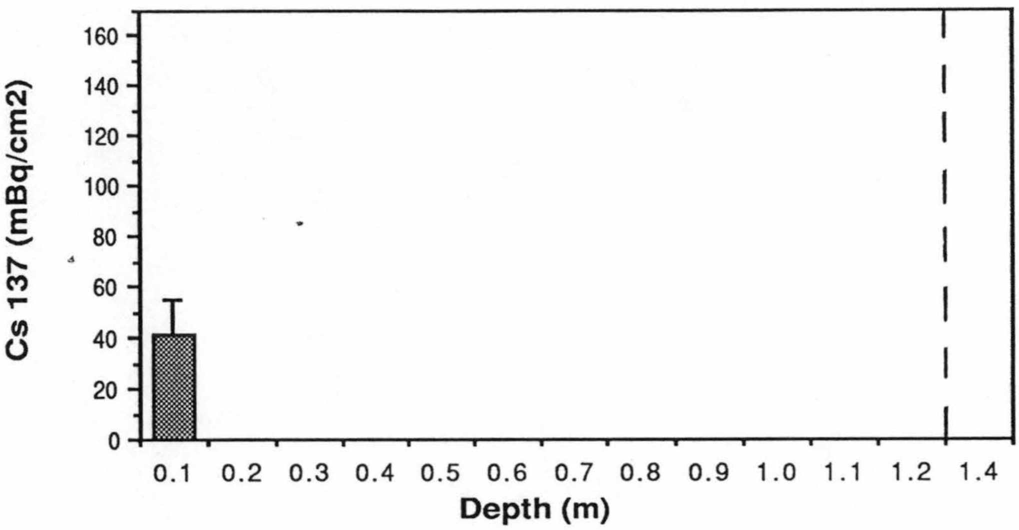


Fig. 4.7 Core O : areal activity vs depth

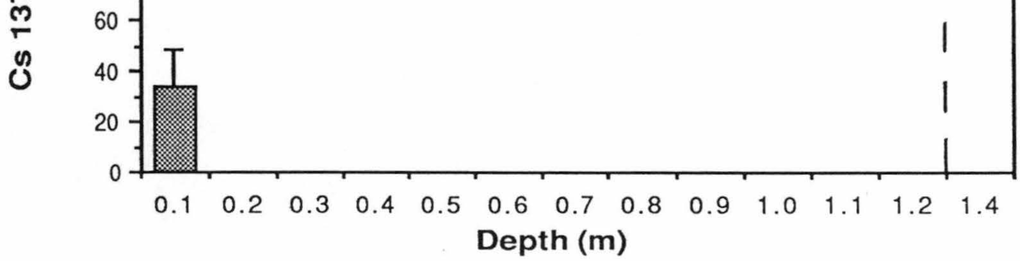


Fig. 4.8 Core Q : areal activity vs depth

Error bars are shown above each histogram; the dotted line shows the depth of the core; values of 0.6 mBq/gm or less are considered non-detectable and have treated as zero

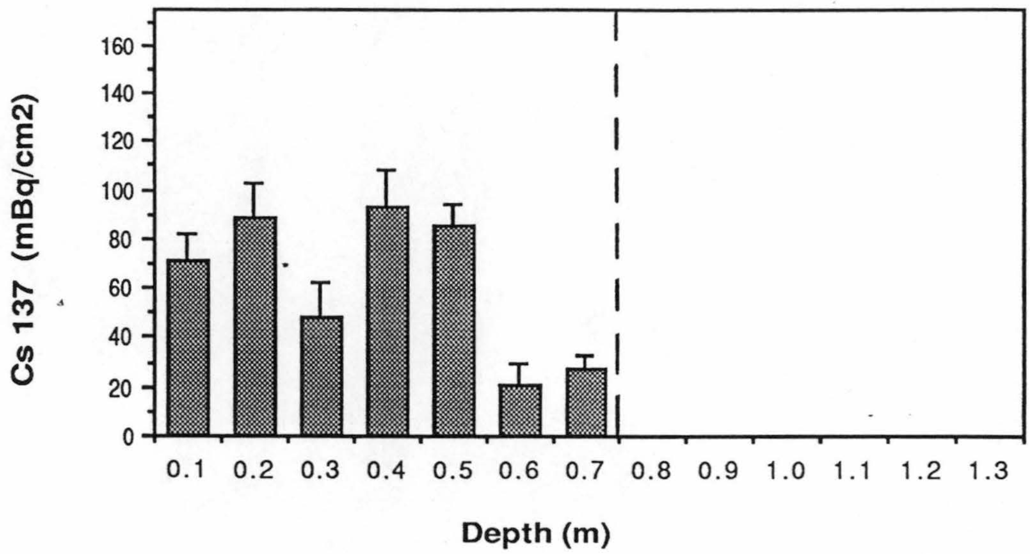


Fig. 4.9 Core R : areal activity vs depth

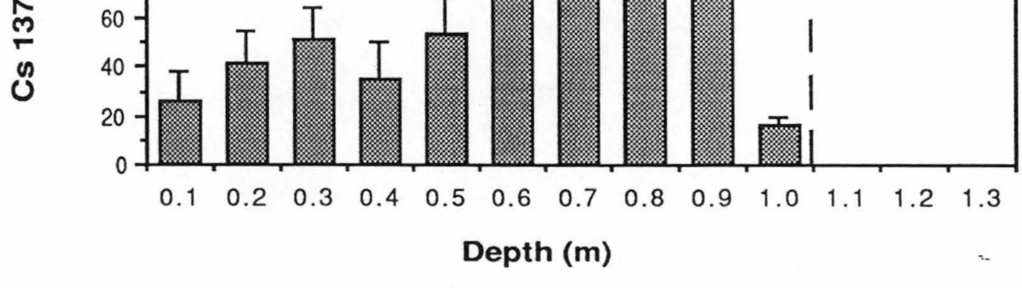


Fig. 4.10 Core S : areal activity vs depth

Error bars are shown above each histogram; the dotted line shows the depth of the core; values of 0.6 mBq/gm or less are considered non-detectable and have treated as zero

Cores K, L, M, N, R and S had total areal concentrations of 459.5, 436.5, 421.7, 370.3, 434.1 and 648.5 mBq cm^{-2} respectively compared with an average reference value for the region of 77.6 mBq cm^{-2}, suggesting considerable sediment deposition since 1954. Cores K and L showed non-detectable levels in the top 30 cm, and below 0.9 and 1.0 m which represents the interface when ^{137}Cs was deposited in significant quantities into the environment and can therefore be dated as 1954.

Core M showed non-detectable levels at 0-10 cm, 20-30 cm and 40 - 50 cm before again showing a modern sediment, or pre 1954 interface, at 1.0m depth.

Core N showed non-detectable levels in the top 20 cm but appears not to have gone deep enough to intersect the 1954 interface.

The various peaks visible in the bay profiles will be discussed in section 4.3.3.

Cores O and Q, taken on the western side of the transect showed areal activities of 40.8 ± 13.6 and 33.3 ± 14.8 mBq cm^{-2} respectively, and significant ^{137}Cs only in the top 10 cm of the sediment profile. Cores R and S did not show any increments with non-detectable ^{137}Cs levels.

Results of activities for samples from Natone Hill, Gordons Hill and Pilchers Hill are shown in Fig 4.11, 4.12 and 4.13. Samples from the northwest slope of Natone Hill (sites V1 to V6) showed sites of erosion and deposition. Sites V1, V2 and V5 had activity of 36.6 ± 4.6, 32.4 ± 2.7 and 20.0 ± 4.7mBq cm^{-2} respectively, while site V3 had an activity of 176.5 ± 6.6 mBq cm^{-2}. Site V4 (74.7 ± 3.1 mBq cm^{-2}) and V6 (75.9 ± 8.6 mBq cm^{-2}) suggest that these sites are either stable or have been subjected to both erosion and deposition.

Two samples obtained from the summit of Gordons Hill (sites W5 and W6) showed activities of 44.8 ± 4.5 and 55.1 ± 4.7 mBq cm^{-2} respectively giving an average of 49.9 mBq cm^{-2}. In comparison with the established average reference value of 77.6 mBq cm^{-2} obtained from a composite of three samples from Pilchers Hill, it is apparent that this area of the hill was relatively stable compared with Natone Hill. The northeast slope of Gordons Hill, where four samples were taken (W1, W2, W3, W4 see Table 4.2 and Fig 4.2) areal activities of 34.7 ± 2.9, 42.3 ± 3.4, 47.3 ± 4.4 and 38.1 ± 6.1 mBq cm^{-2} were recorded suggesting some erosion on the lower slopes.

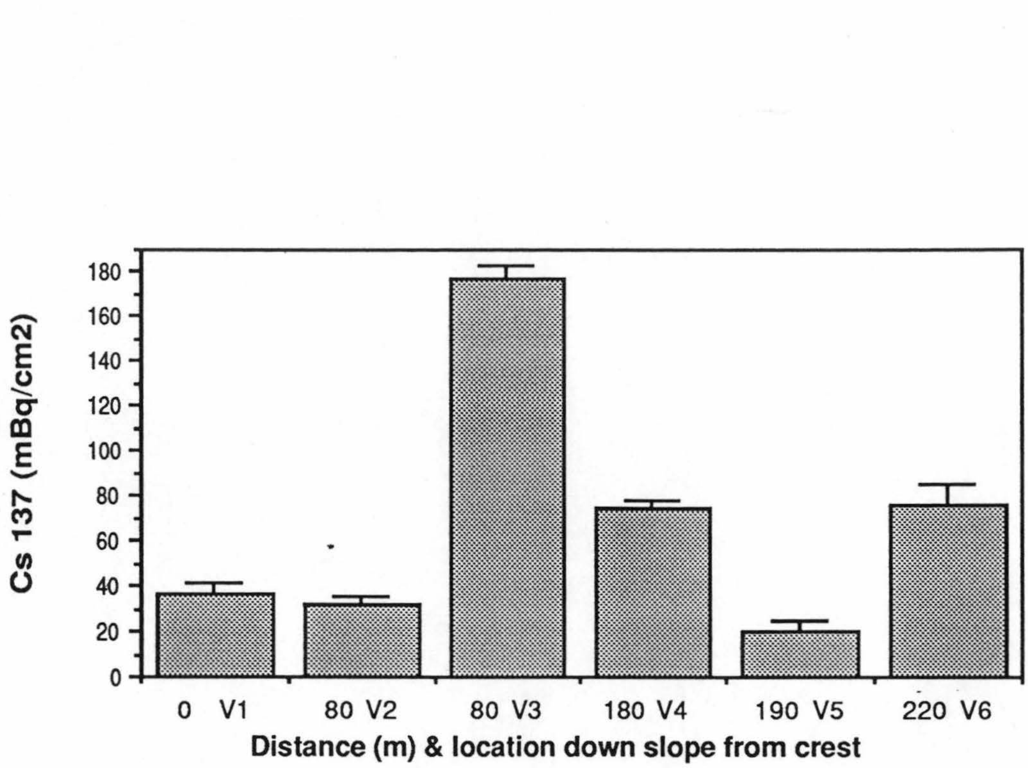


Fig. 4.11 Natone Hill : areal activities at various slope locations

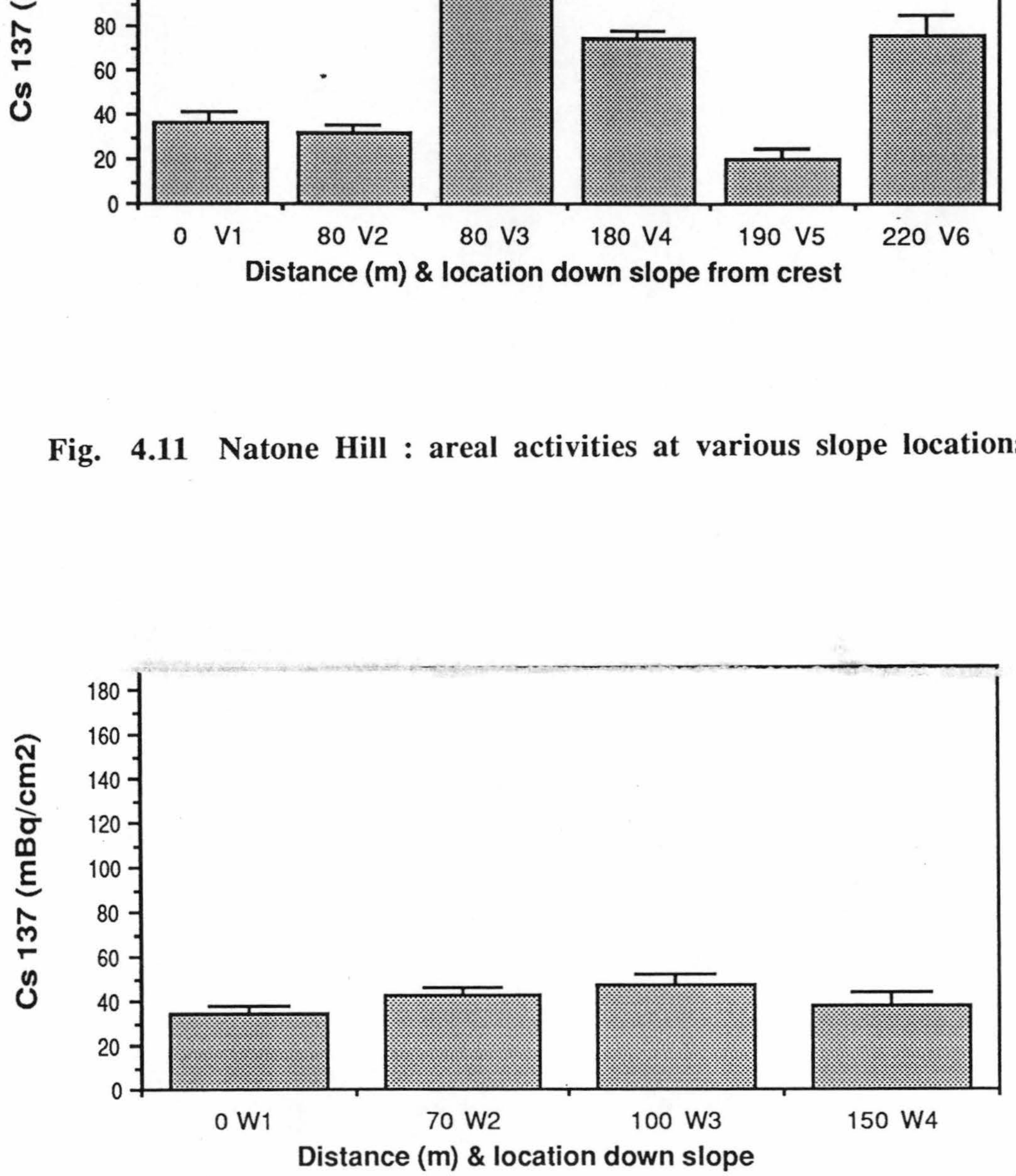


Fig. 4.12 Gordons Hill : areal activities at various slope locations

Error bars are shown above each histogram; locations refer to those in Fig 4.2 and discussed in text

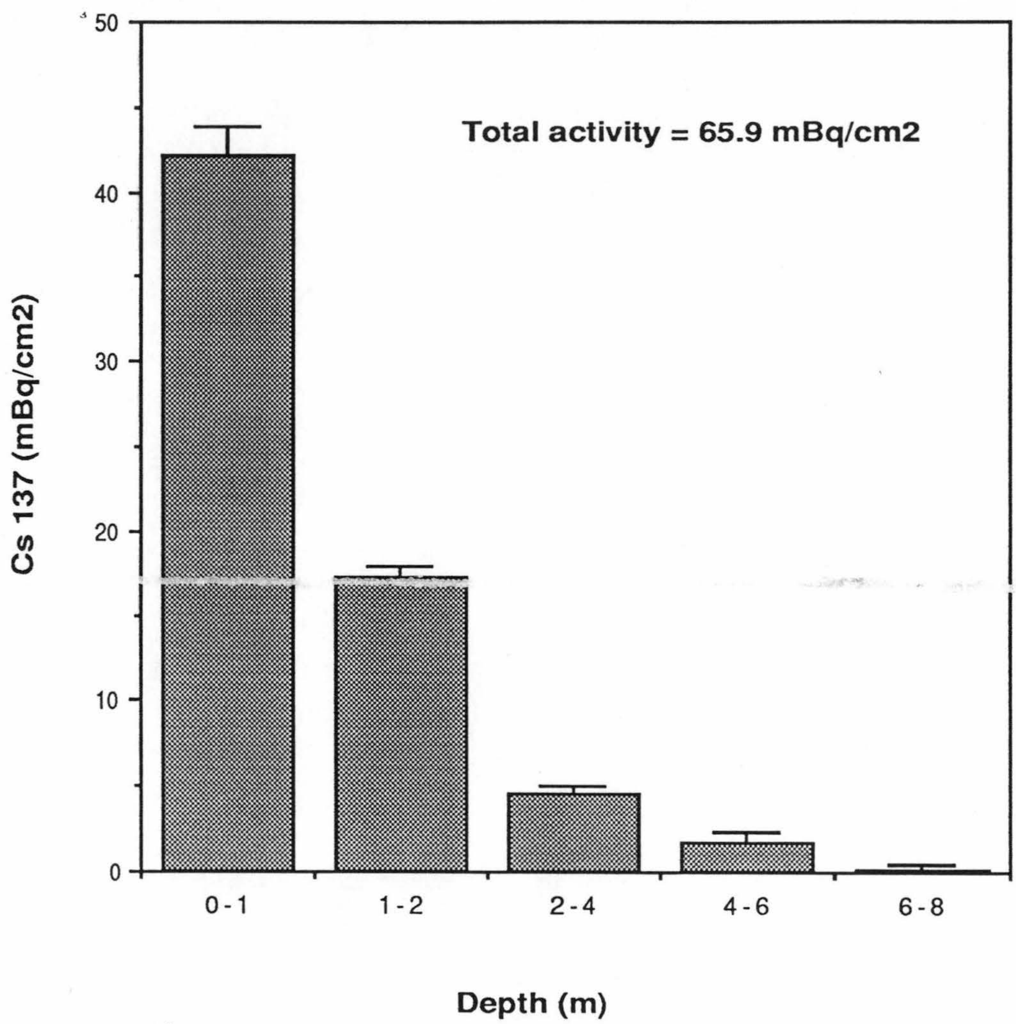


Fig. 4.13 Pilchers Hill : areal activities vs depth

Error bars are show above each histogram

4.3.3 Dating by redistribution of ^{137}Cs - discussion

Cores K, L and M show reduced ^{137}Cs levels at 0.9, 1.0 and 1.0m depths respectively (Figs 4.3, 4.4, 4.5). Negative values were obtained and are theoretically possible because average background levels are taken into account and are subtracted from counts obtained. This zone of transition from positive to negative values has been referred to as the modern sediment interface (Figs 4.3, 4.4, 4.5) and represents the location in the sediment profile where significant quantities of ^{137}Cs were introduced. This interface has been commonly referred to in the literature as the 1954 point (Ritchie & McHenry 1984) and is one of the key dating points identified by the ^{137}Cs technique. Core N does not show a modern sediment interface because it appears not to have been cored deeply enough (Fig 4.6).

Three other dating points are identifiable in sediments; 1958, a period of high fallout; 1963, when the test ban treaty occurred (Ritchie & McHenry 1984); and 1970/71, when the French series of nuclear tests in the Pacific took place (McCallan et al. 1980, Campbell et al. 1982). Having established the modern sediment interface and assuming a uniform rate of sedimentation in the cored areas, each 100mm increment represents approximately a four year period for cores K, L and M. Applying this assumption to the results of areal activities obtained, the 1958 peak occurs at a depth of 0.7 to 0.8m for core K, at a depth of 0.8 to 0.9m for cores L and M (Figs. 4.3, 4.4, 4.5). The 1962 peak, just prior to the 1963 nuclear test ban treaty, occurs at a depth of 0.6 to 0.7m for core K at a depth of 0.7 to 0.8m for core L and at a depth of 0.6 to 0.7m for core M (Figs. 4.3, 4.4, 4.5). The 1970/71 peak occurs at a depth of 0.4 to 0.5m for core K, at a depth of 0.5 to 0.6m for core L and at a depth of 0.5 to 0.6m for core M (Figs. 4.3, 4.4, 4.5). In summary, assuming a uniform rate of sedimentation, the key dating points and expected sediment deposition rates for cores K, L and M, with the exception of the 1962 peak in core M, correlate well with each other.

As well, the upper increments at depths from 0 to 0.5m in cores M and N show what might be called 'erratic' ^{137}Cs activity (Figs 4.5 & 4.6). It is suggested that these 'erratic' results are very likely due to disturbances to bay sediments by a Clarence Council work program in 1980 in which a backhoe was used to clear sediments from around stormwater drains emptying into the bay near the M and N sites, sufficient to allow stormwater to escape freely. This hypothesis appears to have been confirmed by results from cores K and L which, although near the same drains, are further out from the shore in the intertidal area and beyond the reach of the backhoe.

Cores O and Q from the western side of the bay do not show any significant levels of ^{137}Cs below the top 10 cm (Figs. 4.7, 4.8). This suggests that either insignificant amounts of ^{137}Cs have been deposited since 1954 below 10 to 20cm or that the finer particles with which ^{137}Cs is readily adsorbed are absent and have been leached from the sediments and migrated elsewhere in the Bay. This later explanation is supported by the fact that suspended sediment was observed moving across the bay following a storm and is therefore hypothesised as an explanation for the low ^{137}Cs activity in cores O and Q. This hypothesis has been expanded in the summary that follows. It must however be stated that the dynamics of sediment movement in this small bay are complex and a linear explanation of possible sediment movement is at best rather simplistic.

Cores R and S taken from sites in the Bay away from the transect, showed significant levels of ^{137}Cs to depths of 0.5m and 1m respectively suggesting the deposition of ^{137}Cs since 1954 either directly or via water current movement from other parts of the Bay.

The forest site on Pilchers Hill showed an exponential decay of ^{137}Cs with depth (Fig. 4.13). Such a distribution indicates that the site is reasonably stable and as mentioned represents reference levels for the region. The average reference level of 77.6 mBq cm^{-2} makes an interesting comparison with other sites in Australia. In southwestern Western Australia, levels of 50 - 60 mBq cm^{-2} were determined while the Hunter Valley in NSW showed levels of 100 mBq cm^{-2} (Campbell et al. 1986[b], Loughran et al. 1987, Loughran et al. 1988). The reference levels established by this study concord with other States of Australia however further samples are required to refine the reference value.

Samples taken from the catchment areas show various levels of ^{137}Cs down the slopes of Natone Hill and Gordons Hill (Figs. 4.11, 4.12). For Natone Hill the results suggest that active erosion and transport of sediment is occurring. Site V2 (32.4 ± 2.7 mBq cm^{-2}) showed lower ^{137}Cs levels than reference levels, a result not unexpected because of the visible microterracing. Conversely, site V3 (176.5 ± 6.6 mBq cm^{-2}), although located adjacent to site V2 but without observable microterracing, showed a two and half fold increase in ^{137}Cs activity. Sites V4 (74.7 ± 3.1 mBq cm^{-2}) and V5 (20.0 ± 4.7 mBq cm^{-2}) told a similiar story. Site V5 was located in a gully and by showing extremely low ^{137}Cs levels in comparison to other sites on the slope, was a site of obvious soil erosion. Site V4, not located in a gully and with good grass cover, showed no such signs of erosion and in fact the level of ^{137}Cs suggested a relatively stable site.

Gordons Hill did not show significant variations in ^{137}Cs levels between sites thus indicating that the slopes sampled have not been subjected to the same magnitude of erosion as that on Natone Hill. Nevertheless, the relatively low levels ranging from 34.7 ± 2.9 mBq cm^{-2} (W1) to $47.3 \pm$

4.4 mBq cm^{-2} (W3) suggest that uniform sheet erosion has occurred.

4.3.4 Summary of ^{137}Cs results

The use of ^{137}Cs as a tracer for sediment redistribution in a saltwedge type estuary in southeastern Tasmania has provided the following baseline data:

(a) the technique, applied to deposition zones of Lindisfarne Bay, has shown consistency on the eastern side of the head of the bay to enable some interpretation with the principal features of temporal patterns in mainland Australia; and

(b) An average input or reference value for the region of 77.6 mBq cm^{-2} has been established based on three samples from sites in close proximity to each other on Pilchers Hill.

More particularly, results of ^{137}Cs analysis from Natone Hill indicate that active erosion and deposition of the hill is taking place (Fig. 4.11). Site V2, for example, showed stripping of ^{137}Cs, whereas site V3 showed a two and half fold increase in ^{137}Cs concentrations. Sites V4 and V5 are similiar. Site V5 was located in a gully where the ^{137}Cs depleted levels showed signs of obvious stripping whereas site V4 did not.

Gordons Hill did not show significant variation in ^{137}Cs levels between sites thus indicating that the slope sampled has not been subjected to the same degree of erosion as has occurred on Natone Hill.

Caesium 137 analysis of cores taken from the Bay area indicate that on the eastern side of the Bay (ie cores K, L, M & N), 0.9 to 1.1 m of sediment has been deposited over approximately a 30 year period and this could have occurred at different annual rates determined by environmental factors, such as tidal action, river flow and conditions within the catchment. Information obtained from a study of the land use history of the area has indicated that poor management practices were the norm and that significant historical factors had affected the river by 1954, the date when significant levels of ^{137}Cs were detectable. Yearly variations would, however, be expected due to seasonal factors such as rainfall. It has therefore been assumed that the annual rate of sedimentation remained constant on the eastern side of the Bay between 1954 and 1987. Applying this assumption, a sedimentation rate of 2.7 to 3.3 cm per annum applies to the eastern side.

Conversely, the western side of the Bay at sites O and Q was not found to have significant levels of ^{137}Cs below the top 20 cm of sediment. At site R, located on the western side of the Bay and seaward of sites O and Q, significant levels of ^{137}Cs were observed at a depth of 0.5m. At site S located between the eastern and western sides of the Bay significant levels of ^{137}Cs were detected at a depth of one metre.

Having ascertained from historical records that sediment from the eastern side of the Bay has been deposited since European settlement, it appears that material from the western side of the Bay is being depleted of clay and silt which is possibly being carried and deposited to the eastern side of the Bay. This hypothesis is enhanced by observed dispersion of material from west to east following heavy rain and the fact that currents are mainly wind induced and winds are predominantly from the northwest.

It is further suggested that site R may be receiving material moving out from the northwestern corner of the bay and site S may be receiving material from west to east across the bay. To substantiate the sediment movement hypothesis further sampling would need to be carried out not only around the intertidal zone but across the bay as well.

Another interesting feature of the ^{137}Cs results is the peaks shown in the eastern cores. Cores K,L and M showed peaks in ^{137}Cs at 0.5, 0.6 & 0.6 and at 0.8, 0.9 and 0.9 respectively. It is suggested that these peaks are very likely to be related to peak fallout concentrations in 1970/71 and 1964/65 as discussed in section 4.3.3.

4.4 Heavy metal concentrations

4.4.1 Methods

Heavy metal analyses of 50 gram subsamples of sediments were carried out by the Government Analyst in Hobart, Tasmania. The metal compounds soluble in one molar hydrochloric acid were leached from the samples at room temperature and their concentrations relative to the sediment determined by flame atomic absorption using a Varian Spectic AA-40P instrument.

Specimens taken from subsamples obtained for ^{137}Cs analysis on cores K, L, M, N, O, Q, R and S, as well as from subsamples obtained for grainsize analysis on cores D, F, H & I, were analysed for Cd, Cu, Pb and Zn.

4.4.2 Heavy metals: results and discussion

Results of analyses for Cd, Cu, Pb and Zn for each core are shown in mg/l in Figs. 4.14 - 4.25. Cores K, L and M from the eastern side of the bay tended to show increasing levels of all metals with depth to about 0.9 - 1.0m, after which the levels tended to reduce towards the end of the sediment profile. For core N, on the other hand, concentration of metals continued to increase with core depth. Two distinct peaks were evident at depths of about 0.5 to 0.6m and 0.8 to 1.0m in cores K, L and M for all metals. Core N also had peaks for all metals at a depth of 0.5 to 0.6m, but concentrations continue to increase at a depth of 0.9 to 1.0m. In fact it appears likely that core N was not taken deep enough and therefore did not show the drop in concentrations evident in other cores.

It is suggested that the peaks in concentration of all metals at 0.5m in cores K and N and at 0.6m in cores L and M followed by a drop in concentration with decreasing depth, may well represent the period prior to 1974 when inputs of heavy metals into the river were considerably higher than after 1974. At which time amounts of iron precipitates containing reduced amounts of metals were added to material being dumped at sea rather then released into the estuary. This observation is, of course, based on the assumption that there has been a uniform rate of sedimentation since 1954. The second peak, occurring at 0.8 to 0.9m in core K, 0.9 to 1.0m in cores L and M and at 0.9 to 1.1m in core N, is suggested as being associated with a high production period when discharges to the river where high, and minimum environmental safeguards were applied.

Cores K, L and M all also show the lowest levels for each metal in the bottom of the sediment profile (>1.2m). Since core N was probably not taken deeply enough, the expected lower levels with depth present in K,L and M are not apparent for core N.

Cores taken for grainsize analysis but also subjected to analysis for heavy metals also show peaks for all metals in the 0.8 to 1.2m range (Fig. 4.18 & 4.19). Core D has peak concentrations of Cd, Pb & Zn at 0.85m whereas core F has peaks in all metals at 1.16m. These cores, because they were taken using a long narrow corer, have been subjected to a certain amount of compaction. Thus, some adjustment to depth values has had to be made (eg. if 1.8m of sediment has been removed from a sampling depth of 2.0m, then 0.2m of compaction has taken place). Uniform compaction was assumed and all the figures given here are the corrected figures.

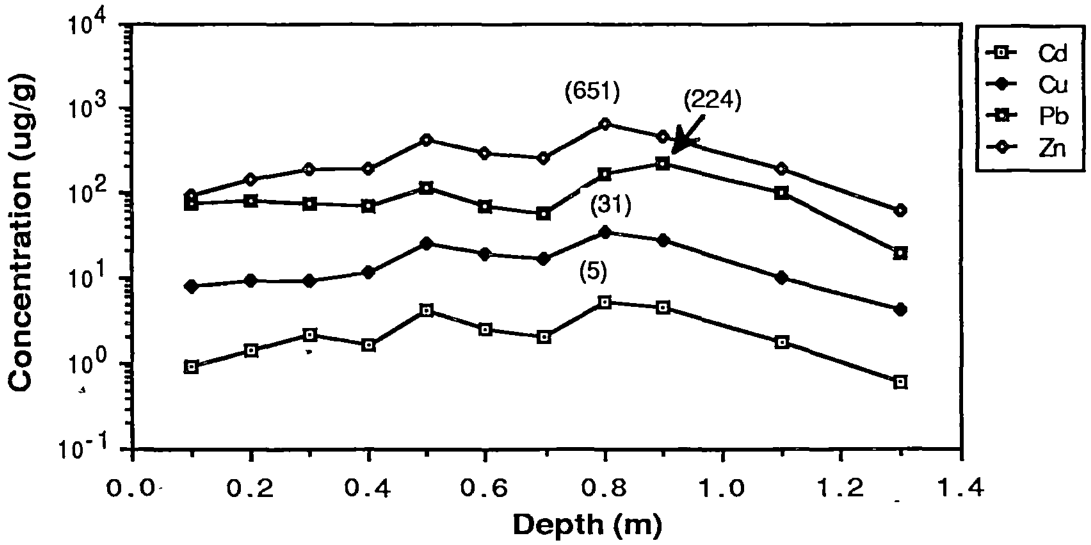


Fig 4.14 Core K : metal concentrations vs depth

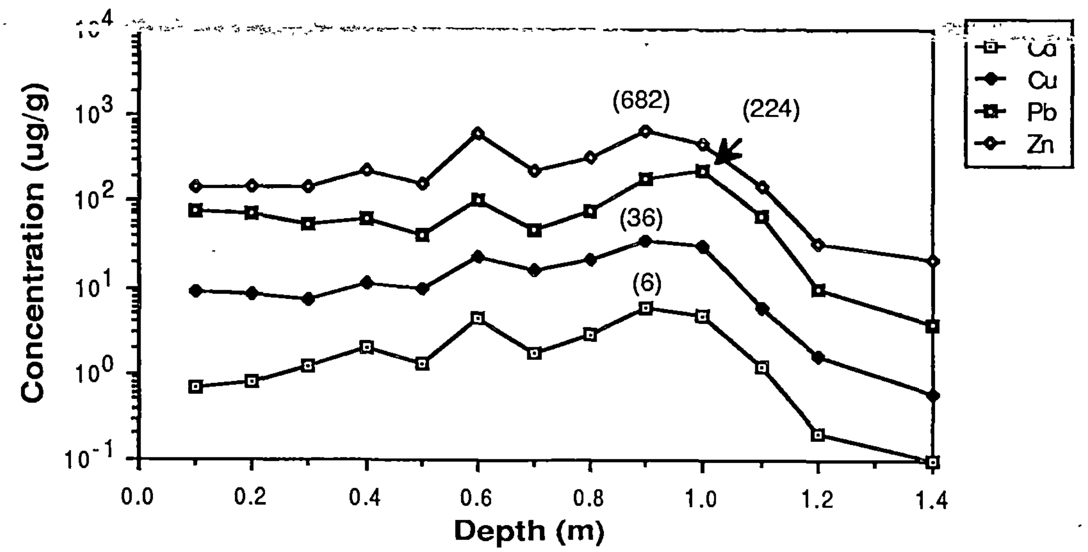


Fig 4.15 Core L : metal concentrations vs depth

Graphs shows metal concentrations on a logarithmic scale against depth; peak concentrations of each metal are shown

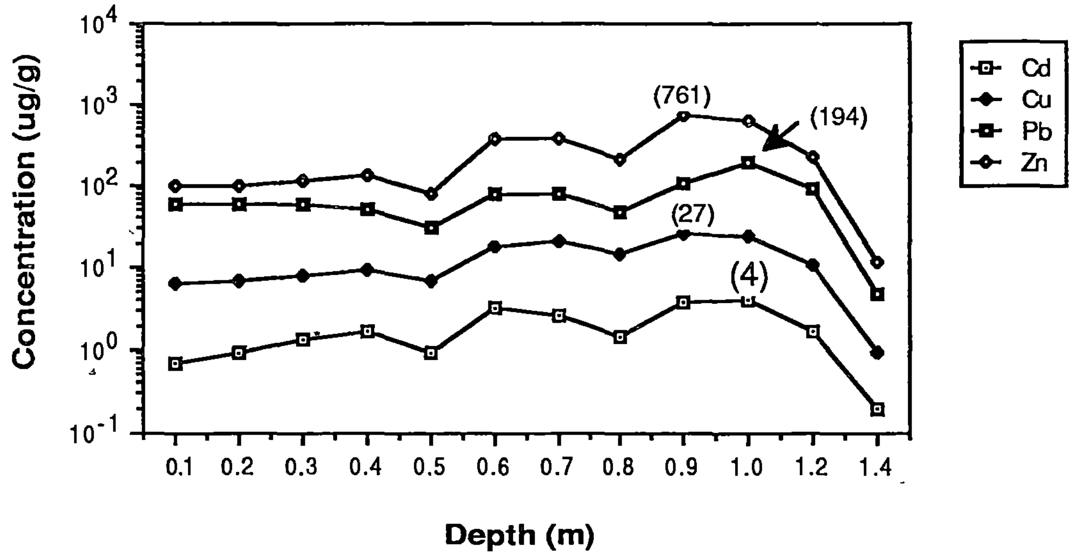


Fig 4.16 Core M : metal concentrations vs depth

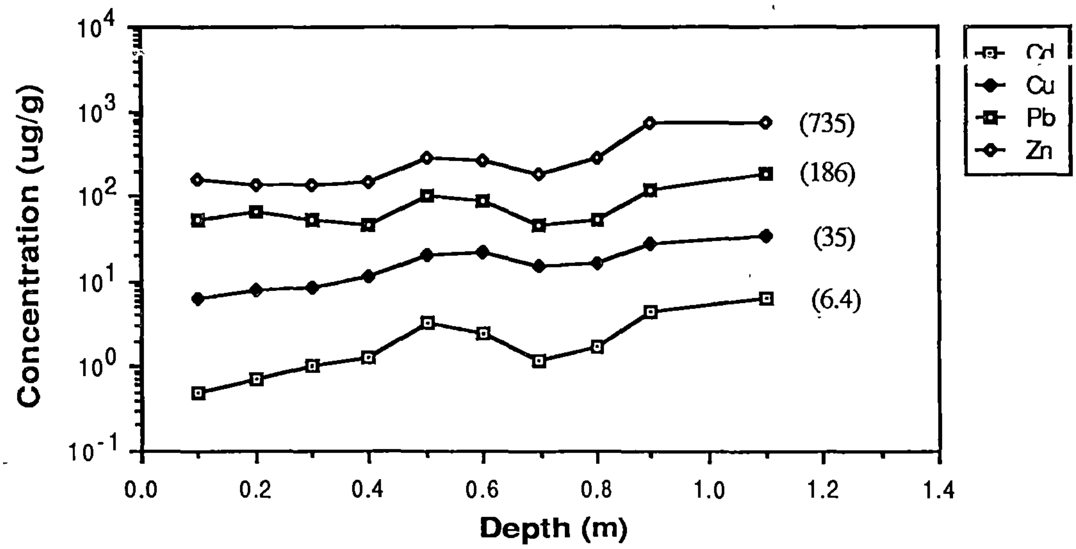


Fig 4.17 Core N : metal concentrations vs depth

Graphs shows metal concentrations on a logarithmic scale against depth; peak concentrations of each metal are shown

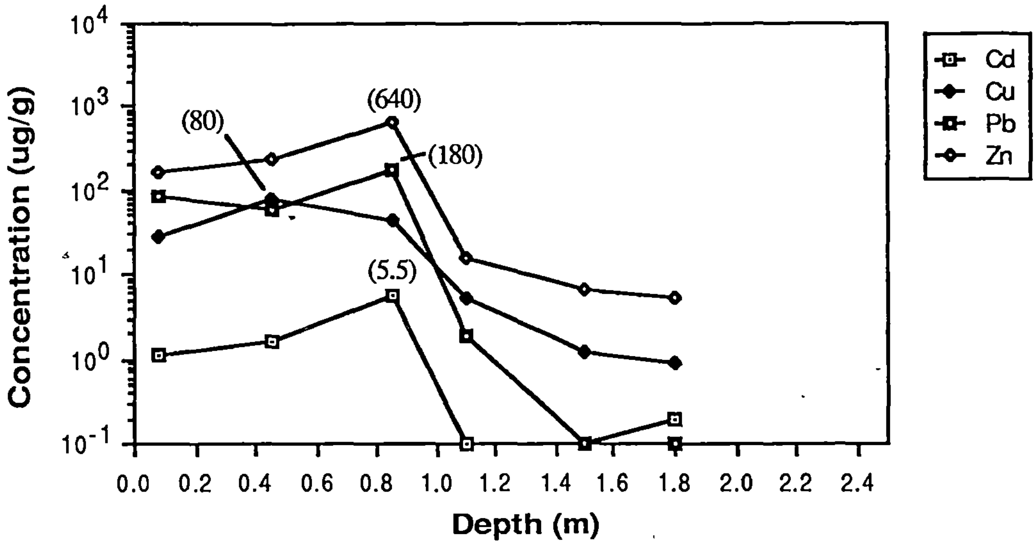


Fig 4.18 Core D: metal concentrations vs depth

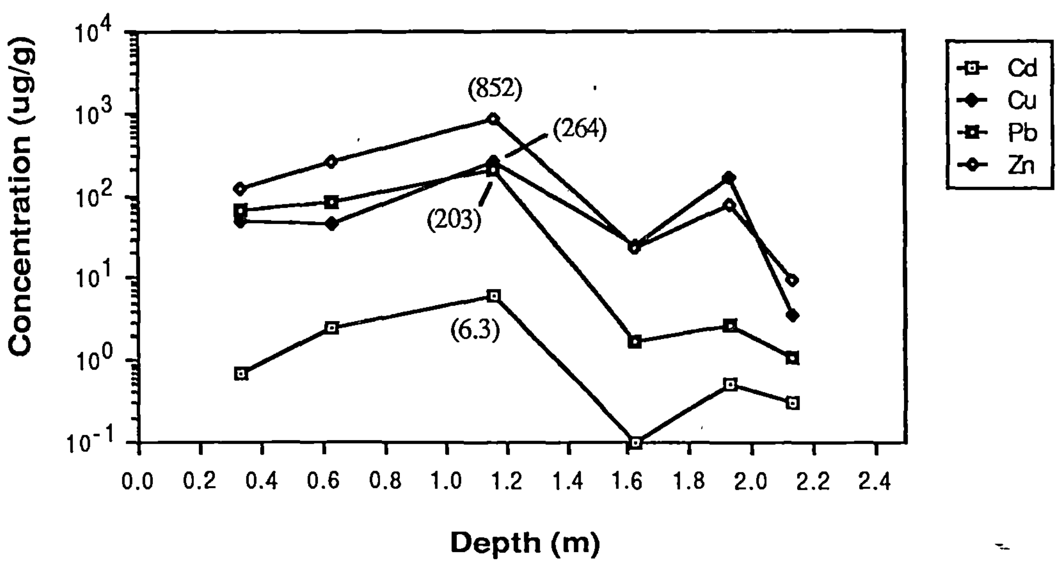


Fig 4.19 Core F : metal concentrations vs depth

Graphs shows metal concentrations on a logarithmic scale against depth; peak concentrations of each metal are shown

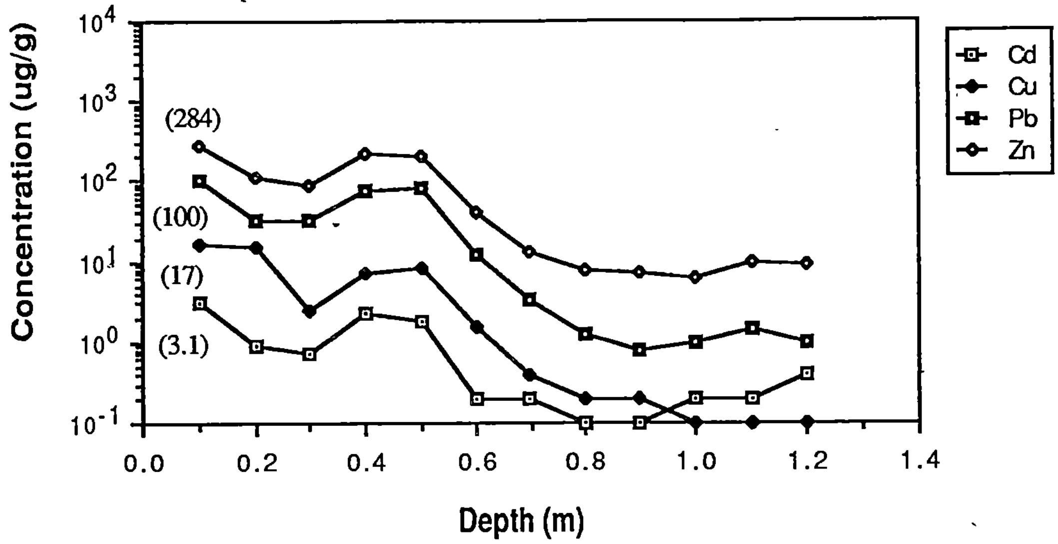


Fig 4.20 Core O : metal concentrations vs depth

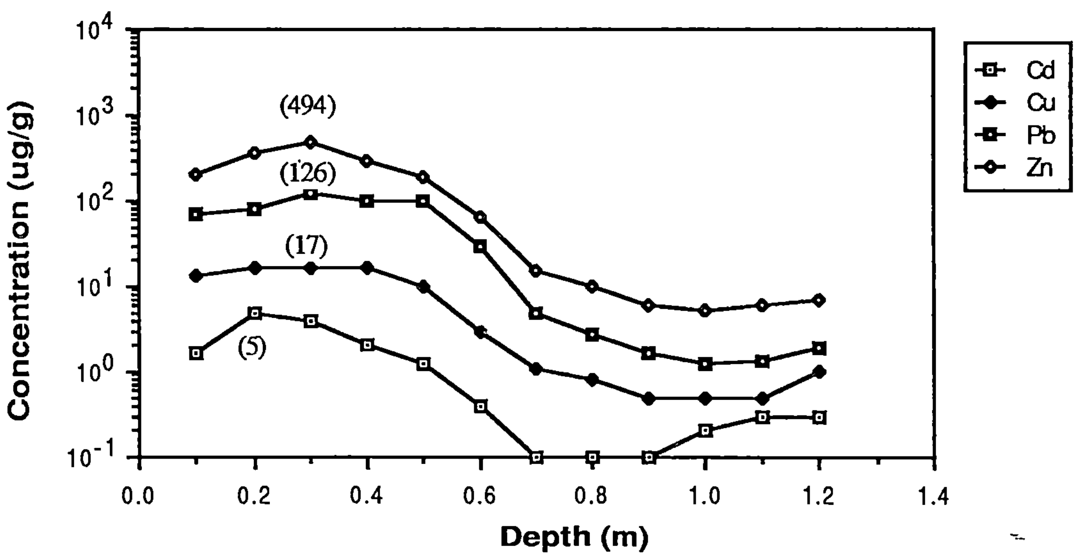


Fig 4.21 Core Q : metal concentrations vs depth

Graphs shows metal concentrations on a logarithmic scale against depth; peak concentrations of each metal are shown

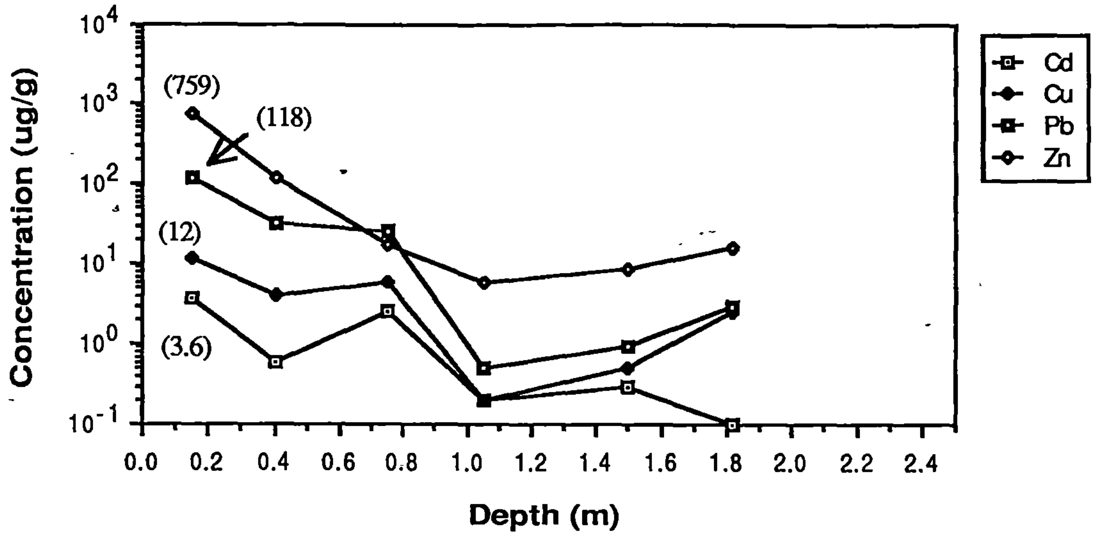


Fig 4.22 Core H : metal concentrations vs depth

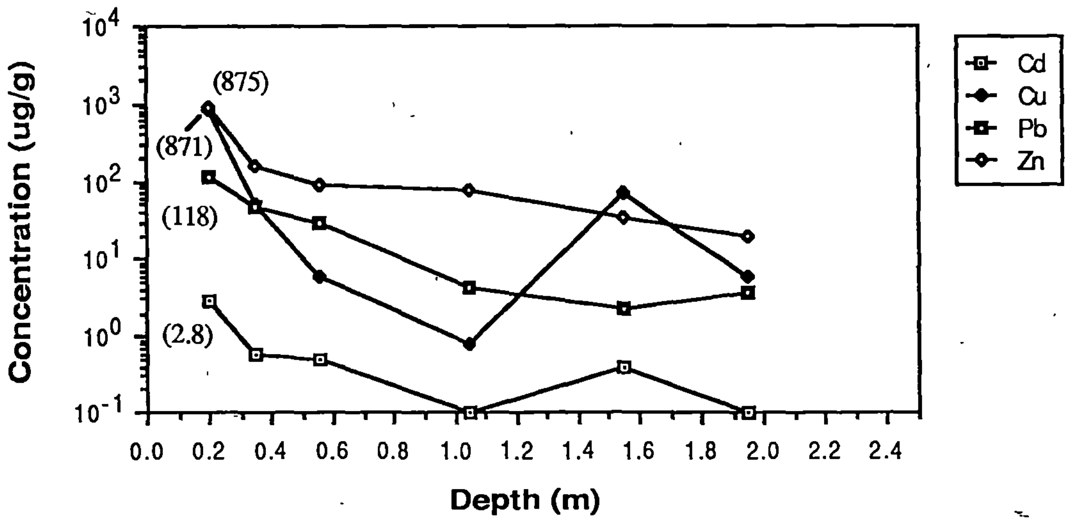


Fig 4.23 Core I : metal concentrations vs depth

Graphs shows metal concentrations on a logarithmic scale against depth; peak concentrations of each metal are shown

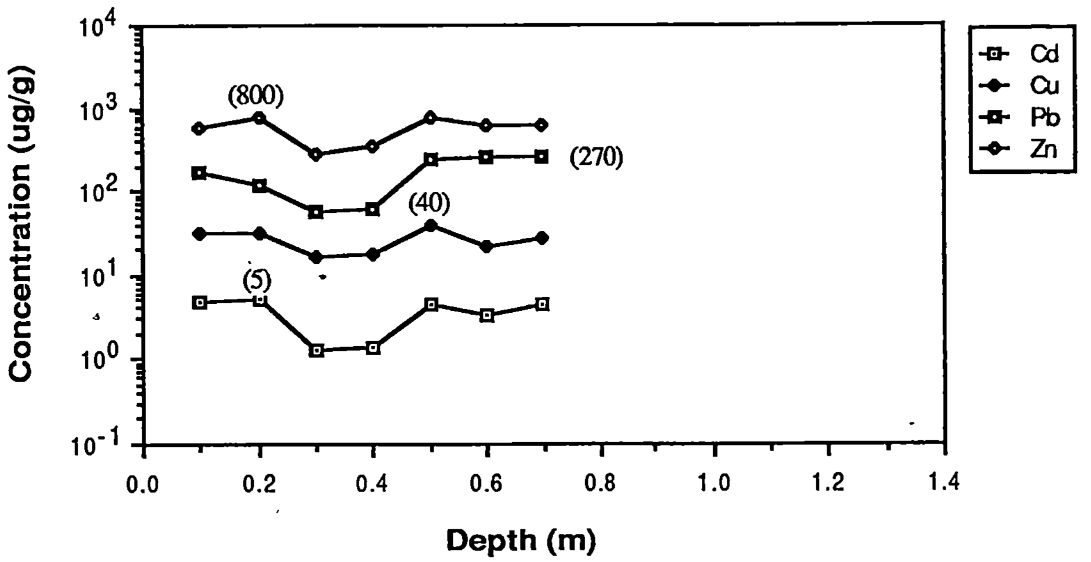


Fig 4.24 Core R : metal concentrations vs depth

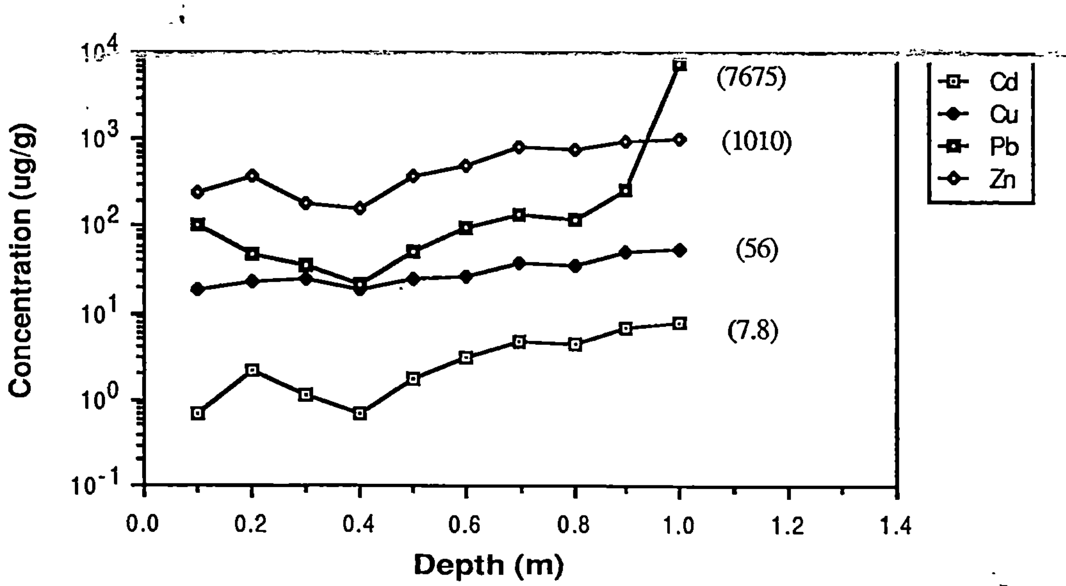


Fig 4.25 Core S : metal concentrations vs depth

Graphs shows metal concentrations on a logarithmic scale against depth; peak concentrations of each metal are shown

Cores from the western side of the Bay tend to show maximum metal levels near the surface of the sediments. Core O has a maximum concentration of all metals at depths of 0 to 0.1m and a second peak at 0.4 to 0.5m (Fig 4.20), whereas core Q shows peak concentrations in all metals except Cd at 0.3m (Fig. 4.21). From these depths, metal concentrations decrease steadily until a depth of approximately one metre is reached where a levelling off takes place. Cores H and I also show highest concentrations in the top 20cm of sediment (Fig. 4.22 & 4.23). However, a second peak similiar to that shown in core Q, was not evident.

It is interesting to note the extremely high concentrations of heavy metals found at the bottom of the sediment profile for cores R and S, especially in core S (Fig. 4.24 & 4.25). The highest Pb and Zn values of all samples analysed, 7675ppm and 1010 ppm respectively, were found at 1m depth in core S. These extremely high values, especially the lead value, may be due to a separate point source in the subsample such as a fragment of a lead sinker.

Core R showed a drop in heavy metal concentration at 0.3m to 0.4 m (Fig. 4.24) for which an explanation could not be given.

4.4.3 Heavy metals - a comparison and extrapolation

Having obtained concentrations of various metals in dated sediments, a comparison was made with known concentrations at a particular time period from other work.

Levels of 50 µg/g (Cd), 335 µg/g (Cu), 1820 µg/g (Pb) and 9120 µg/g (Zn) were found in [illegible] sediment samples taken by Bloom in 1974. These samples were taken from the estuarine floor at the mouth of Lindisfarne Bay. This study has found concentrations for the same time frame at the head of the bay. In Bloom's study, analysis was carried out by which metals were leached by boiling in concentrated nitric acid. In this study, analysis was carried out by leaching with one molar hydrochloric acid. Bloom (1975) however was able to show that different analytical procedures, 'gave substantially the same results.' On this basis. a comparison of the levels obtained in 1974 by Bloom at the mouth of the Bay and those found at the head of the Bay and dated as 1974 has been undertaken (Table 4.3).

Table 4.3 Comparison of metals in sediments

	Cd	*Cu*	*Pb*	*Zn*
mouth of Lindisfarne Bay (Bloom 1975) [1]	50	335	1820	9122
mean of cores K, L,M and N at 0.5-0.6m dated as1974 [2]	3.8	2.2	100	424
amount increase between mean of 4 cores at head of bay & mouth of bay	x 13	x15	x18	x21

NOTES [1] Data from one core sample collected in 1974 from the top few cm of the estuarine floor using a 16 cm Barcoo pipe dredge, dried and finely ground and analysed by leaching in concentrated HNO3 (Bloom 1975).

[2] Sediments obtained in this study by a 10 cm coring device, dried and sieved to two mm and analysed by leaching in one molar HCL.

[3] All units are in µg g-1

Assuming that:

(a) a uniform rate of sedimentation has occurred between 1954 and 1987;

(b) concentrations are comparible between different methods;

(c) the 0.5 to 0.6 m depth increment in cores K,L,M and N represents the period around 1974 ;

(d) the estuarine floor at the mouth of the Bay has been subjected to sedimentation; and

(e) samples from the mouth of the bay had similiar amounts of silt and clay as the head of the bay it is apparent that concentrations have been diluted by a factor of between 13 and 21 for four metals in the estuary between the mouth and the head of Lindisfarne Bay. It could therefore be stated that deposition of metals from upriver into the head of the Bay compared with the mouth of the Bay is considerably less. Assuming sediment deposition follows the same pattern as particulate metals, it may be inferred that the main river catchment is not a major contributor to sediments in the head of the bay as concluded by Lewis and Duvivier (1988).

4.5 Pesticides residues

As was noted when examining the past land use practices in the Lindisfarne Bay area (Section 2.2),crops, including apricot orchards, were a permanent feature of the catchment's landscape. Associated with crop production was effective pest control measures including the use of suitable pesticides. The use of chlorinated hydrocarbons such as DDT were common practice after World

War Two (Tasmanian Department of Agriculture pers. comm.). This group of chemicals are known to be very persistent in the environment (Khan 1980).

As a consequence of suspected run-off of pesticide residues from soils into the bay, analyses were carried out by the Government Analyst in Hobart by extraction with n-hexane prior to analysis by gas chromotography with an electron capture detector. Sixty five species taken from subsamples obtained for ^{137}Cs analysis on cores K, L, M, N and O were analysed and contained less than 0.1 parts per million of the organochlorine pesticides Lindane, Aldrin, Dieldrin and DDT. The persistence of the chemicals in various substances is of the following order: orchards > vegetables > tobacco > field crop sites (Khan 1980). Levels of Dieldrin residues in soils were > 0.1 ppm after 10 years but by far the most persistant organochlorine has been DDT, which decays very slowly and may well approach the 35 year half life (Khan 1980). The time for 95 percent disappearance in soils at average active dosages is four to 30 years.

The results obtained were therefore not unexpected as they clearly show that the sediments in the bay were not polluted with pesticide residues. Following initial results, this aspect of the study was not pursued any further.

4.6 Grainsize analysis

4.6.1 Methods

Grainsize analysis forms an important part of an investigation of sediments and it is with this technique that important conclusions as to the size of the clastic particles as they are deposited can be obtained. Such analyses are often difficult since clastic sand grains may become cemented into tough aggregates, and clay minerals may tend to cluster in clumps due to their flakier character and surface electric charge.

Results of grainsize analyses are usually plotted and curve data summarised by means of various mathematical parameters allowing ready comparison between samples. Such parameters as mean, standard deviation, skewness and kurtosis are said to be useful in describing various grainsize characteristics, although the sedimentological significance of these measures is not fully known (Folk 1974).

If samples contain more than a few percent of material finer than 0.0625mm (the upper limit of silt), it is usually necessary to separate the sediment into two fractions. The coarser material is usually analysed by sieving and the finer material either by pipette analysis or by using the hydrometer technique. When most of the material consists of sands then dry sieving maybe carried out following drying and disaggregation. Wet sieving is recommended where much clay type material occurs. However, wet sieving techniques are slow and messy.

Cores for grainsize analysis were taken as deep as possible at sites shown in Fig 4.1. At approximately 2.0 m, a clay layer was struck which formed a bung in the end of the corer, thus preventing sampling to greater depths. Once all material was removed from the corer, the sediment profile of cores was seen to be stratified. Samples were therefore taken from each of the strata and at different locations along the strata. In all six specimens were removed from each core for analysis.

Samples obtained for grainsize analysis were in an aggregated state following drying. Preliminary disaggregation therefore preceded subsampling to 50 mm using a version of the Jones sample splitter described by Krumbein and Pettijohn (1938). Final disaggregation was obtained using a mortar and rubber pestle. As the sediments were mainly of a coarse to medium grained nature, there were no disaggregation problems such as becoming cemented into tough aggregates.

The grade scale most commonly used for sediments is the Wentworth Scale (Folk 1974), for which the phi(ø) unit (Krumbein and Pettijohn 1938) is a convenient way of presenting data. The range chosen for sieve analysis was from -4ø (16mm) to +4ø (0.0625mm) with intervals of 0.5 ø giving a range of 14 different grainsizes.

Each sample was mechanically shaken for 15 minutes. Following sieving, particle size fractions were weighed and calculated as a percentage of the total weight. The basis of the classification involved two stages : (a) initial plotting according to Folk's triangle (1954); and (b) cumulative curves.

Firstly, the proportions of gravel (material coarser than 2 mm), sand (material between 0.0624 mm and 2 mm) and mud (defined as all material finer than 0.0625 mm i.e. silt plus clay) were plotted on a triangular diagram (Folk 1974) (Fig 4.20). Fifteen major textural groups are defined by the triangle. To place a specimen in one of the 15 groups, only two parameters need to be determined:

(a) how much gravel it contains with boundaries at 80, 30 and five percent; and
(b) the ratio of sand to mud (silt plus clay) with boundaries at 9:1, 1:1 and 1:9. (Fig 4.26)

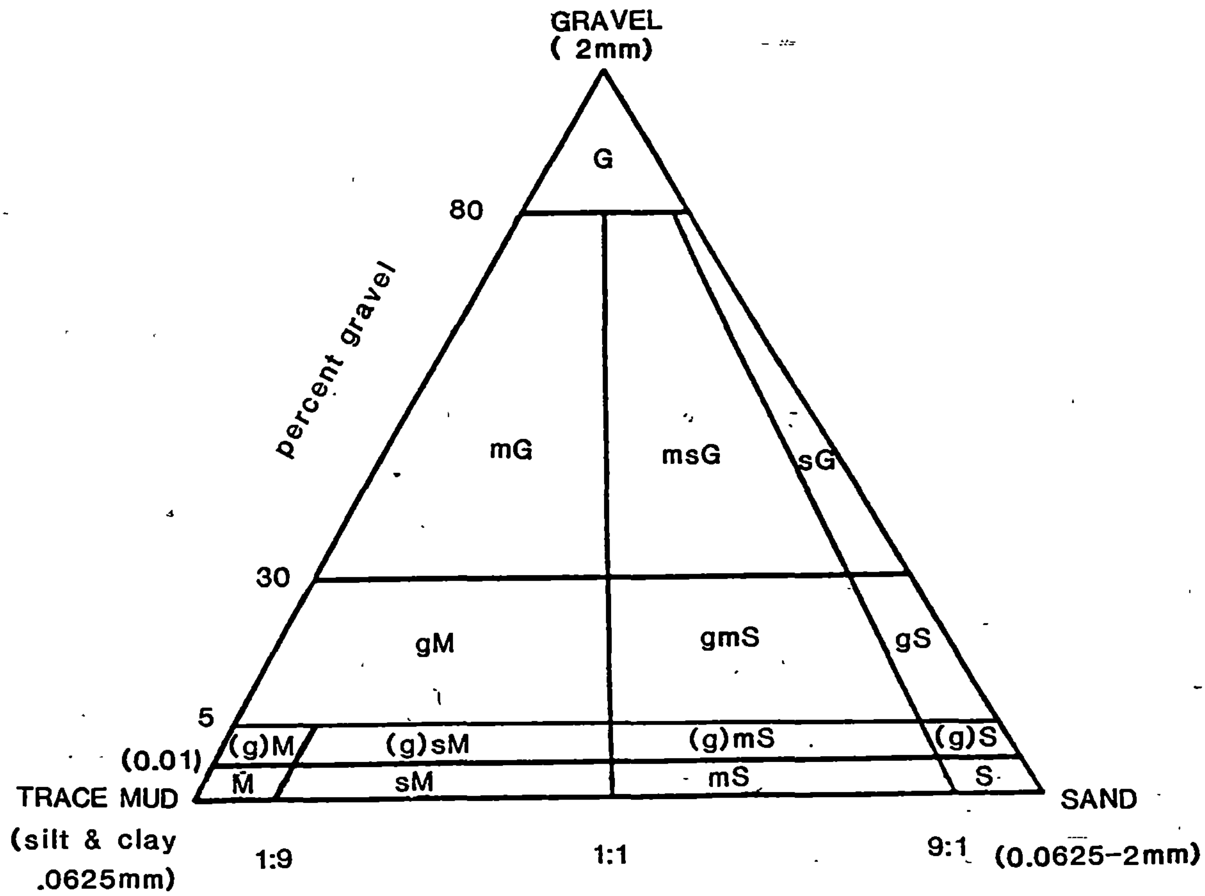


Fig 4.26 Folks classification of sediments

Fifteen major textural groups are represented by various symbols shown; for example sG is sandy gravel, gS is gravelly sand and (g)S is slightly gravelly sand; the bottom line indicates the ratio of sand to mud (silt plus clay) with boundaries at 1:9, 1:1, and 9:1; the left hand side indicates percent gravel with boundaries at 80, 30 and 5 percent; sediments from the eastern side of the bay occurred in a different textural group to those from the western side of the bay

source : Folk 1974

Secondly, data obtained from grainsize analyses have been plotted in graphical form. Histograms, cumulative curves with arithmetic ordinates, cumulative curve with probability ordinates, and frequency curves are the most common ways of plotting such information.

The cumulative curve with probability ordinate gives a perfectly straight line for a sediment following the normal, symmetrical probability distribution. This occurs because the probability scale is very condensed in the middle of the scale (30-70 percent) and very much expanded at the ends (under 10 percent and over 90percent) thereby straightening out the sigmoidal curve which would be expected if arithmetic ordinates were used. This type of curve is valuable for studying departures of sediments from a normal distribution (Folk 1974), and therefore have been be used for determination of all parameters in this study.

To evaluate the sets of samples it is probably best to compare the sediment curves directly by eye as only in that way can their entire character be evaluated. However, this procedure can be inconvenient and is somewhat subjective and certainly not quantitative. To solve this problem, recourse is therefore made to various statistical measures which quantitatively describe certain features of the curves.

There are two basic methods of obtaining statistical parameters useful to grainsize analysis. The most commonly used method involves plotting the cumulative curve for the sample and reading from the curve percentages of grains of given sizes. The second method, called the method of moments, 'is far more complicated and probably of no greater value' (Folk 1974).

Consequently, four statistical measures have been utilised for grainsize analysis in this study, namely mean, standard deviation, skewness, and kurtosis. The description and method of calculation of each of these measures are described below.

(a) Mean

Average grainsizes can be calculated in many different ways which can give quite different estimates of average. There appears to be no consensus as to which method is best to use. The graphic mean (Mz), however, is considered to be adequate (Folk 1974) and is defined by the percentile relationships:

$$Mz = \frac{Ø16 + Ø50 + Ø84}{3} \quad \text{(Folk 1974)}$$

where Ø16 etc is the Ø value corresponding to 16 percentile

(b) Standard deviation

Uniformity, or sorting, of sediments can be measured by calculating their graphic standard deviation (∂_I) where:

$$\partial_I = \frac{Ø84 - Ø16}{4} + \frac{Ø95 - Ø5}{6.6} \quad \text{(Folk 1974)}$$

Values of ∂_I, obtained for a large number of sediments, suggest that the classification scheme shown in Table 4.4 is useful for the assessment of sorting quality.

Table 4.4 Classification by sorting

∂I	*Classification*
under .35ø	very well sorted
.35ø - .5ø	well sorted
.5ø - .71ø	moderately well sorted
.71ø - 1.0ø	moderately sorted
1.0ø - 2.0ø	poorly sorted
2.0ø - 4.0ø	very poorly sorted
over 4.0ø	extremely poorly sorted

(c) Kurtsosis

For the normal or Gaussian probability curve, the phi(ø) diameter interval between the ø5 and ø95 points should be exactly 2.44 times the interval between the ø25 and ø75 points (Folk 1974). Thus, if the sample curve plots as a straight line on probability paper (ie if it follows the normal curve), the ratio will be 2.44 and the distribution is said to have a normal kurtosis (1.00). Departure from a straight line changes the ratio, and kurtosis or peakedness is the quantitative measure used to describe this departure from normality. Kurtosis thus estimates the ratio between sorting in the 'tails' of the curve and sorting in the central portion. If the central portion were better sorted than the tails, the curve is said to be excessively peaked or leptokurtic. Alternatively, if the tails are better sorted than the central portion, the curve is said to be flatly peaked, or platykurtic. Graphic kurtosis (Kg) is represented by the relationship:

$$Kg = \frac{Ø95 - Ø5}{2.44(Ø75 - Ø25)} \qquad \text{(Folk 1974)}$$

and estimates 'for a given spread between ø25 + ø75 points, by how much the ø5 to ø95 spread is deficient ?' (Folk 1974).

A classification system has been developed based on values of graphic kurtosis, and shown below in Table 4.5.

Table 4.5 Classification by kurtosis

Kg	*Classification*
<0.67	very platykurtic
0.67-0.9	platykurtic
0.9-1.11	mesokurtic
1.11-1.5	leptokurtic
1.5-3.0	very leptokurtic
> 3.0	extremely leptokurtic

(d) Skewness

The degree to which distributions are skewed or distorted can be measured by calculating the skewness (Sk) which is determined from the relationship:

$$Sk = \frac{Ø16 + Ø84 - 2(Ø50)}{2(Ø84 - Ø16)} + \frac{Ø5 + Ø95 - 2(Ø50)}{2(Ø95 - Ø5)} \quad \text{(Folk 1974)}$$

Symmetrical distribution curves have zero skewness (Sk = 0), whereas those with excessive amounts of fine material (i.e. a tail to the right) are positively skewed and those with excessive amounts of coarse material (i.e. a tail to the left) are negatively skewed. The more the skewness departs from zèro, the greater is the degree of assymmetry.
Again, a classification scheme can be suggested, based on values of Sk Table 4.6.

Table 4.6 Clasification by skewness

Sk	*Classification*
+1.00 - +.30	strongly fine skewed
+.30 - +.10	fine skewed
+.10 - -.10	near symmetrical
-.10 - -.30	coarse skewed
-.30 - -1.00	strongly coarse skewed

4.6.2 Grainsize results and discussion

As stated above, sediment profiles exhibited marked stratification, therefore providing convenient criteria for selection of samples for grainsize analysis.

Core D from the eastern side of the bay had four distinct strata. Core F, also from the eastern side of the bay, had three strata similiar to those of core D but did not have the yellowish/grey clay layer found at the bottom of the sediment profile, presumably because sampling was not deep enough. Core I had seven distinct strata and core H had five. Both H and I were from the western side of the bay. Notable in these western cores was the presence of gravelly material near the surface. As well both cores I and H had yellowish grey clay at the bottom of the sediment profile.

A small amount of compaction of the sediment during sampling was unavoidable. Thus, although the corer was inserted to a depth of 2 m, only 1.8 m of material was extracted. To allow for this, it has been assumed that compaction was at a uniform rate, and all samples have been adjusted to actual depth by proportionally scaling up from the depth of material obtained.

Results from sample proportions of gravel, sand, silt and clay together with percentiles and statistical proportions are given in Table 4.7.

Results from sample sievings enabled cumulative curves to be constructed for each stratigraphy subsampled from the cores collected. From these graphs, the fifth percentile, 16th percentile, 25th percentile, 50th percentile, 75th percentile, 84th percentile and 95th percentile values have been obtained (Table 4.8). Thus the normality of samples could be assessed.

As stated previously, samples may be classified into 15 classes according to Folk (1974) (Fig 4.26). Using this initial classification, samples in this study were found to fall into four classes : gS, (g)S, (g)mS and sG. These together with examples of usage are given in Table 4.8 and are shown in Table 4.7.

Table 4.8 Classes of bay sediments according to Folk

Major textural class		*Examples of usage*	*Cores*
(g)S	slightly gravelly sand	slightly granular medium sand	D & F
	slightly conglomeratic sandstone	slightly pebbly coarse sandstone	
gS	Gravelly sand	pebbly coarse sand	H & I
	conglomeratic sandstone	granular very fine sandstone	
(g)mS	slightly gravelly muddy sand	slightly pebbly muddy medium sand	
	slightly agglomeratic muddy sandstone	slightly cobbly fine sandstone	endH&I
sG	sandy gravel	sandy pebbly gravel	end D
	sandy conglomerate	sandy boulder conglomerate	

source: Folk 1974

Sample	Percentile													
number	5	16	25	50	75	84	95	mean	stdev	skew	kurt	Sand	Silt & clay	Gravel	Class
	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø	ø	%	%	%	
D1	0.25	1.8	2.1	2.46	2.75	2.95	3.5	2.4	0.78	-0.21	2.05	96.5	2.5	1.0	(g)S
D2	-0.95	1.7	2.05	2.6	3.25	3.6	4.1	2.63	1.24	-0.21	1.72	91.6	8.0	0.4	(g)S
D3	0.00	1.45	1.8	2.37	2.9	3.1	3.8	2.31	0.99	-0.16	1.42	95.2	3.0	1.8	(g)S
D4	-0.10	1.5	1.9	2.45	2.95	3.2	3.8	2.38	1.02	-0.2	1.52	95.0	3.0	2.0	(g)S
D5	-0.75	1.5	1.9	2.55	3.05	3.2	3.9	2.45	1.15	-0.29	1.66	91.5	4.0	4.5	(g)S
D6	-2.50	-2.5	-2.4	1.5	2.6	3.05	4.1	0.68	2.39	-0.42	0.54	64.0	5.6	30.4	sG
F1	1.05	1.65	1.95	2.25	2.75	2.95	3.35	2.28	0.67	0.01	1.18	98.6	0.4	0.1	(g)S
F2	0.50	1.7	1.95	2.3	2.7	2.9	3.4	2.3	0.74	-0.11	1.58	97.8	0.2	0.2	(g)S
F3	0.02	1.6	2.1	2.6	3.05	3.3	4.1	2.5	1.04	-0.19	1.76	93.5	1.5	0.5	(g)S
F4	0.60	1.6	1.85	2.4	2.9	3.1	3.6	2.37	0.83	-0.11	1.17	98.3	1.2	0.5	(g)S
F5	0.80	1.6	1.9	2.4	2.95	3.2	3.8	2.4	0.85	-0.03	1.17	95.8	3.0	1.2	(g)S
F6	-1.75	1.2	1.7	2.45	3	3.25	3.9	2.3	1.37	-0.37	1.78	90.0	3.5	6.5	gS
H1	-3.20	-1.6	-0.65	1.25	2.2	2.55	3.4	0.73	2.04	-0.46	0.95	77.5	1.5	21.0	gS
H2	-1.80	-0.4	0.3	1.52	2.2	2.4	2.95	1.47	1.42	-0.45	1.02	87.6	2.4	11.0	(g)S
H3	-0.70	0.8	1.25	2	2.45	2.85	3.42	1.88	1.14	-0.24	0.41	94.4	1.6	4.0	(g)S
H4	-0.30	0.9	1.2	2.05	2.7	2.95	3.65	1.97	1.11	-0.15	1.08	94.0	3.0	3.0	(g)S
H5	-2.50	0	1.1	2.1	2.9	3.3	4.1	1.8	1.83	-0.38	1.5	82.5	7.0	10.5	gS
H6	-0.30	0.4	0.95	2.2	3.35	4	4.25	2.2	1.59	-0.05	0.78	82.5	17.0	0.5	(g)mS
I1	-1.40	0.4	1.1	1.9	2.6	2.95	4	1.75	1.46	-0.21	1.48	88.5	5.0	6.5	gS
I2	-2.50	-1.9	-1	0.3	1.4	1.8	2.5	0.07	1.68	-0.21	0.85	73.7	1.3	25.0	gS
I3	-1.25	0.3	0.9	1.6	2.15	2.4	3.1	1.43	1.18	-0.29	1.43	92.0	2.0	6.0	gS
I4	-0.65	0.6	1.1	1.9	2.5	2.8	3.55	1.77	1.19	-0.2	1.23	93.5	3.0	3.5	(g)S
I5	-2.70	-0.6	0.5	1.7	2.5	2.8	3.6	1.3	1.8	-0.45	1.29	84.0	2.0	14.0	gS
I6	0.00	1	1.4	2.4	3.3	4	4.25	2.47	1.39	-0.04	0.92	84.0	15.7	0.3	(g)mS

Table 4.7 Results of grainsize analysis

Core D had slightly gravelly sand along most of its sediment profile. At 1.8m. it had gravelly sand and below this was clay.

Core F had slightly gravelly sand down its entire sediment profile with sandy gravel occurring at the bottom of the core.

Core I was dominated by gravelly sand in its upper layers changing to slightly gravelly sand in its lower layers. Slightly gravelly muddy sand occured at 1.8m.

Core H had gravelly sand on its surface with slightly gravelly sand below, changing back to gravelly muddy sand at 1.4 m. At 1.86 m slightly gravelly muddy sand was evident. Following this initial simple determination, one might stop at this point and say no more about grainsize. However more information can be gained by further data analysis.

Hence percent cumulative frequency curves of grainsizes, graphed on a log/linear scale for each core were undertaken and the four statistical measures previously mentioned were determined.

It was evident that cores D and F had similar classes of sediment, and slightly gravelly sand occurred along most of the sediment profile. Cores H and I also had similar profiles where gravelly to slightly gravelly sand occurred in the upper layers changing to slightly gravelly muddy sand towards the base of each core.

Eastern cores (D and F) had generally higher mean values than the western cores (H and I). Mean values of cores D and F were around 2.4ø with the exception of sample D6 which was 0.68ø and consisted of 30 percent gravel. Mean values of cores H and I were more scattered and generally lower than cores D and F. Samples H6 and I6 had high proportions of silt and clay and therefore had higher mean values.

To compare sample means, a Students t-Test was performed on unpaired samples from the means of cores D and F with cores H and I. The bottom samples D6, F6, H6 and I6 were excluded from the comparison because these mostly consisted of clay. The comparison showed $t_{10} = 4.049$; $p < 0.05$ therefore rejecting the hypothesis that the samples came from populations with the same means.

With reference to skewness and kurtosis, cores showed characteristics outlined in Table 4.9:

Table 4.9 Skewness and kurtosis characteristics

CORE			
F	**D**	**I**	**H**
coarse to very coarse skewed	coarse skewed	becoming very coarse skewed	strongly coarse skewed
leptokurtic to very leptokurtic	very leptokurtic	leptokurtic	mesokurtic to leptokurtic with depth

In summary, the cores taken for grainsize analysis had characteristics shown in Table 4.10

Table 4.10 Summary of grainsize characteristics

	D	F	H	I
textural class (see Table 4.8)	(g)S	(g)S	gS	gS
average grainsize mean excluding bottom layers	2.43ø	2.37ø	1.51ø	1.26ø

This grainsize work was not carried out on cores obtained for ^{137}Cs analysis because information was sought on the grainsize characteristics of the entire sediment profile of about two m. Cores taken for ^{137}Cs were to depths of only 1.2m. However the cores taken were adjacent to ^{137}Cs core sites and enable an understanding of the grainsize characteristics between the eastern and western side of the bay.

4.7 Synthesis of ^{137}Cs and heavy metal results

The concomitancy of results of ^{137}Cs redistribution and heavy metal concentrations are such that a synthesis of their degree of concordance is possible. Earlier parts of this chapter have provided explanations for the results obtained which have been summarised below.

For cores K, L and M respectively:

(a) depths of 0.9, 1.0 and 1.0 m represent the period 1954/55 when significant quantities of ^{137}Cs were first detected;

(b) depths of 0.7 to 0.8, 0.8 to 0.9 and 0.8 to 0.9m represent the 1958 peak of ^{137}Cs fallout; and

(c) depths of 0.4 to 0.5, 0.5 to 0.6 and 0.5 to 0.6m represent the period about 1970 when a series of French nuclear tests in the Pacific occurred.

For cores K and L respectively:
(d) a peak at depths of 0.6 to 0.7 and 0.7 to 0.8 correlates with the period 1962-63 of maximum fallout and just prior to the nuclear test ban treaty.
And more generally:

(e) a peak occurring at 0.5 (cores K & N) and 0.6 (cores L & M) followed by a drop in concentration represents the period 1974 when heavy metals into the river were considerably higher than post 1974 when amounts of iron precipate containing reduced amounts of metals were added to material being dumped at sea;

(f) concentrations of heavy metals at depths of 0.9 (core K) and 1.0m (core L & M) reflect the period of lower production of ore concentrate and consequent discharges of wastes from the EZ plant (ie pre 1955);

(g) a peak of all metals at 0.8 to 0.9m (core K) and 0.9 to 1.0m (cores L and M) reflect the period of high production (1964 when 106,940 tonnes of ore concentrate were produced [North Broken Hill 1965]);

(h) concentrations of metals in sediments between 0 and 0.5m in cores K, L and M showed reduced but continuing deposits;

(i) core sites O, Q, R and S showed varying ^{137}Cs activity highlighting the complex patterns of sediment movement in this small bay;

(j) non-detectable ^{137}Cs activity at below 0.2m in cores O and Q suggest either leaching of finer particles from the profile or a lack of ^{137}Cs deposition; low heavy metal concentrations at depths below 0.5 m suggest non deposition in the region; and

(k) reduced activity of ^{137}Cs in core S at 1.0 m, suggesting approachment to the modern sediment interface, concord with high heavy metal levels at this depth, also observed in cores K, L, M and N.

Cores K, L and M were the only cores to indicate the modern sediment interface (1954) essential for undisputed interpretation of the results of the ^{137}Cs technique and so have been used for further examination.

To clarify the above observations, a graphical representation of metal concentration together with activity for a typical core, against estimated time in years was carried out (Fig 4.27). Core L was selected as being typical of results obtained. The attached notes to Fig 4.27 explain the correlation.

Having assumed a uniform rate of sedimentation, it was desirable to compare obtained redistribution patterns with depth (and time), with known ^{137}Cs fallout for the region. Hence mean activity from cores K, L and M and mean fallout of ^{137}Cs from Melbourne for the period 1960 to 1980 were graphed against time in years (Fig 4.28). Unfortunately fallout for the period pre 1960 and post 1980 could not be obtained at the time of writing. As can be seen, a close relationship exists for the period shown. The lag in the graph could represent the period between deposition in the catchment and transport to the intertidal interface; it could also highlight the annual varying rates of sediment deposition. Nevertheless, the redistribution of ^{137}Cs in sediment on the eastern side of the head of the bay is in concordance with the mean fallout of ^{137}Cs for Melbourne.

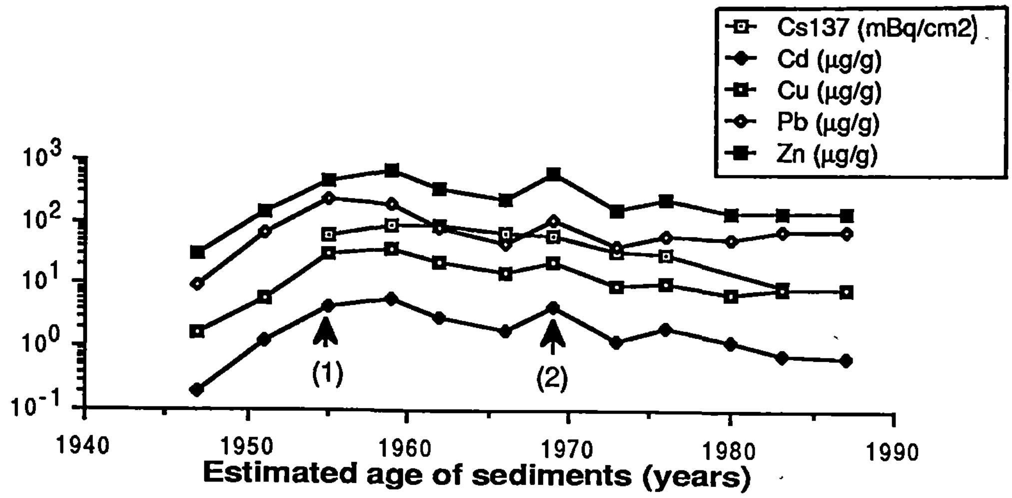


Fig. 4.27 Core L : ^{137}Cs & heavy metals over time

Core L was selected as a typical core for illustrative purposes to show the features of heavy metal accumulation in sediments against estimated years established by ^{137}Cs dating; two features are evident namely:
(1) 1954, periods prior to this were characterised by low Zn production and subsequent discharge from EZ to the river; (2) 1970 - 1973, new metal recovery process and commencement of jarosite dumping at sea resulting in reduction in metal discharges to the estuary

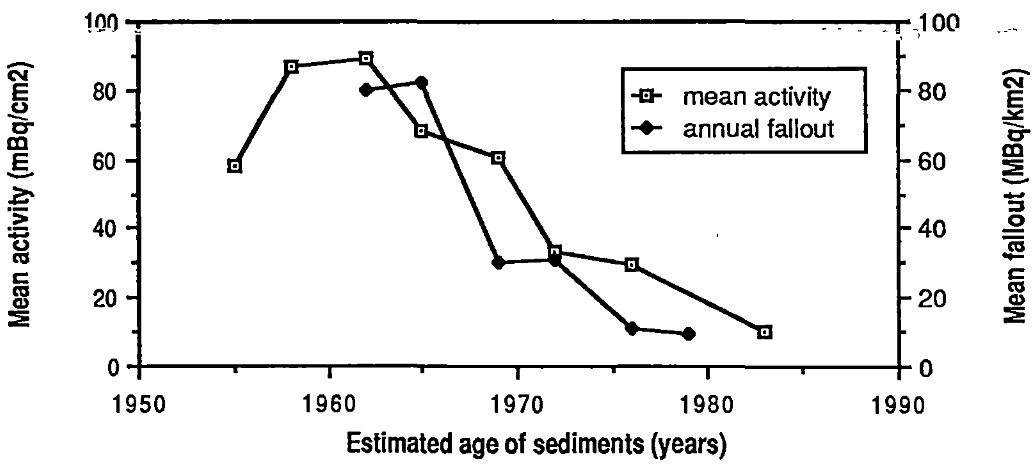


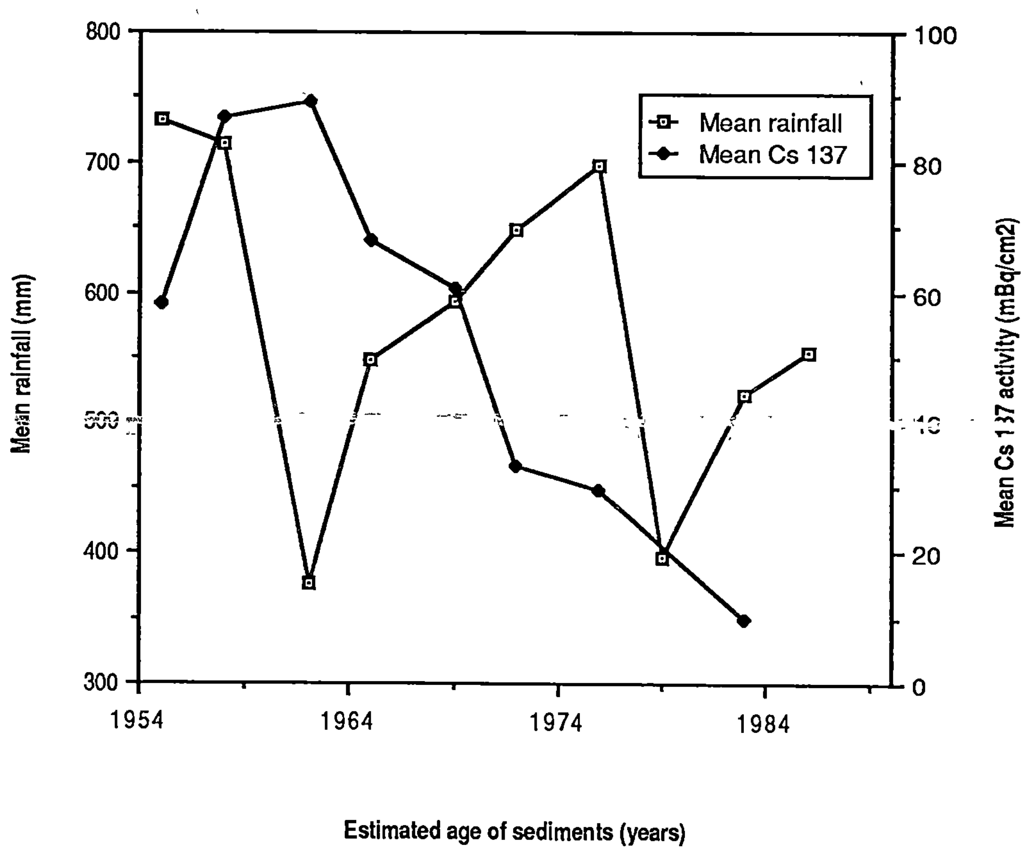
Fig. 4.28 ^{137}Cs redistribution & ^{137}Cs fallout versus time

A comparison was made of mean activity from cores K, L and M and mean fallout of ^{137}Cs from Melbourne for the period 1960 to 1980; the lag in the graph may be due to the delay beween fallout and redistribution; a good correlation was evident signalling consistency with the principal features of temporal patterns on mainland Australia

Davis (1963 cited in Wise [1980]) found that the concentration of Cs137 varied with latitude, and that within a given latitudinal zone fallout was a linear function of annual rainfall. Wise (1980) went on to say:

> This is important, as fallout figures are available for only a few stations, but by using mean annual rainfall figures the input to the system at most locations can be estimated.
>
> Wise (1980)

To that end, mean annual rainfall and mean ^{137}Cs activity of cores K, L and M were graphed against time (Fig 4.29).



4.29 ^{137}Cs redistribution & rainfall versus time

A comparison was made of mean activity for cores K, L and M and mean rainfall at Lindisfarne for the period 1954 to 1986; rainfall varied between approximately 375 (1962) and 730 (1955)mm; mean activity varied between 90 (1962) and 10 (1983) mBq/cm2; no relationship was found

Rainfall recorded at Lindisfarne showed erratic annual fluctuations for the period, of between approximately 375 and 730mm, and ^{137}Cs activity varied between 10 and 90 mBq/cm^2. It was apparent that the fallout of ^{137}Cs was not related to rainfall from this linear comparison. However the variable of quantities of ^{137}Cs fallout was not included in the comparison. If a comparison was made between the three variables, quantities of fallout, rainfall and activity at ground level at a number of sites, a relationship could be shown. It is suggested that further work is needed in this area.

The effects of salinity and desorption on uptake of ^{137}Cs are aspects of the work not discussed in detail here but are worth noting. Hayes & Sackett (1987) when studying ^{239}Pu, ^{240}Pu, ^{238}Pu and ^{137}Cs concentrations in tidal marsh estuaries found that the ratios of $^{239,240}Pu$: ^{137}Cs were about three times higher than would be predicted for fallout deposition rates, indicating desorption of ^{137}Cs from particles encountering the saline water of the sea (Olsen et al. 1981, cited in Hayes & Sackett [1987])

CHAPTER 5

SUMMARY AND MANAGEMENT OPTIONS

5.1 Major land use changes affecting sedimentation within the bay.

Lindisfarne Bay has changed from a bay containing foreshore beaches and unpolluted waters to a situation where landfill has altered its original coastline; unsightly sediment from the river and bay catchments dominates its foreshore during low tide and its waters are now not considered suitable for swimming. From historical records, these changes appear to have occurred over a period of approximately 150 years with most occurring over the past forty plus years.

A surge in building and land clearance for agriculture occurred during the period 1901-1910. The greatest amount of activity, however, has occurred in the period since the 1950s. The bridging of the Derwent Estuary to provide a road link between the eastern shore and Hobart, the commencement of industries such as the EZ Works and the building of hydro-electric dams have provided a stimulus for development. Associated with this development and inherent with western thinking has been the ethic of dominion over the land (White 1967). The fragile and highly erodible soils, as defined in Davies (1987), in the catchment of Lindisfarne Bay and other bays along the Derwent Estuary have been subjected to indiscrete land use practices such as wholesale clearing, regular burning and subdivision development. The increased sedimentary load thus entering the bays and the Derwent River generally has resulted in considerable siltation. The problem of siltation and river water pollution has also been accentuated by discharges of poorly treated sewage and industrial wastes.

With the opening of the floating bridge in 1943, an alteration of the currents in the estuary, which are predominantly wind affected, appeared to have interfered with the dynamics of marine sediment action (Plate 1.2). The removal of the floating bridge coincided with sand deposits reappearing on the foreshores in and around Lindisfarne Bay. By 1950 the head of Lindisfarne Bay became a dumping ground because of massive deposition of sediment. Eventually, a rock wall was built across the head of the bay in 1964 and the area behind was reclaimed.

Also in 1964, the commissioning of the Poatina Dam meant that waters from Great Lake and its catchment were diverted northwards away from the Derwent. This single event probably had the greatest impact on river flow. This and other dams on the upper and lower Derwent have created a means of controlling the flow of the river. Thus, since 1964, the lowest flows recorded in the river have been 25 cumecs. This compares with seven cumecs prior to 1964.

Soundings in the bay were taken in 1978 at the request of the local sailing club because of difficulty with navigation in shallow waters. Comparison of the soundings taken in 1978 with further soundings taken in 1986 as part of this study have indicated that deposition levels have increased by as much as 0.3m in the last eight and a half years thus suggesting a relatively high rate of accretion.

Unfortunately it is only when a problem directly affects people that thinking is directed to the causes and possible remedies; the formation of the Lindisfarne Bay Beautification Committee in 1985 is evidence of this.

5.2 The use of ^{137}Cs in determining sedimentation rates

This study has achieved its principle aim of determining sedimentation rates in Lindisfarne Bay by dating sediment cores, taken at various sites in the Bay, using the ^{137}Cs technique. The results obtained show that between 0.9 and 1.1m of sediment has been deposited on the eastern side of the bay during the last 33 years. This equates to between 2.7 and 3.3cm per year (cm/yr) assuming a uniform rate of sedimentation. At first glance these levels might appear to be extremely high. However soundings taken in 1978 and again in1986 in the head of the Bay showed that about 0.3m of sediment was deposited in this period (Fig3.9). This equates to approximately 3.5 cm/yr and is similar to the rate determined by ^{137}Cs analysis.

Sedimentation rates have been obtained for comparison with other researchers using ^{137}Cs as a dating tool (Campbell et al. 1982, McHenry & McIntyre 1984), (see Table 5.1).

Table 5.1 Sedimentation of Water Bodies Determined by ^{137}Cs Redistribution

study area	*sedimentation rate*	*source*
Reelfort Lake, Tennesse, USA	0.6 cm/yr	McHenry & McIntyre 1984
Fort Cobb, Oklahoma USA	4.6 cm/yr	McHenry & McIntyre 1984
Maluna Creek, NSW Australia	2.3 cm/yr	Campbell et al. 1982
Lindisfarne Bay, Tasmania,Australia	2.7 to 3.3 cm/yr	this study

This table was included to highlight the fact that the ^{137}Cs technique can be applied to many different environments for determination of sedimentation rates.

Lakes in America dated by McHenry & McIntyre (1984) show rates of sedimentation ranging from 0.6 cm/yr (Reelfort Lake, Tennessee) to 4.6 cm/yr. (Fort Cobb, Oklahoma). As well, in an area under viticulture at Maluna Creek Basin in New South Wales, extensive dating of sediments has been carried out on a range of sites (Campbell et al. 1982). This work (Loughran & Cambell 1983, Campbell et al. 1986a, Campbell et al. 1986b) was aimed at reaching a sediment budget for the vineyard, an unprecedented aim for any area using the ^{137}Cs technique. Areas of sediment accumulation indicated that 65cm of material was deposited between 1954 and 1982 which equates to 2.3cm/yr (Table 5.1).

Interpretation of results obtained using the ^{137}Cs technique have inherent problems and assumptions. Time lags occur between the time of atmospheric deposition of ^{137}Cs and the time of deposition of ^{137}Cs in the sediment profile. This time lag would be expected for the processes of erosion, transport and deposition to take place. Work carried out on the sediment profile of a reservoir in the USA (Ritchie et al. 1974) has indicated a time lag of six to 12 months between the time of ^{137}Cs fallout and its deposition in the sediment profile. In Australia research on the redistribution of ^{137}Cs by erosion and deposition (McCallan et al. 1980) suggests that although ^{137}Cs fallout is related to rainfall, the relationship is not constant, varying spatially over time. Nevertheless, the overall fallout from year to year is similar throughout Australia and indeed the world (McCallan et al. 1980).

Reworking or mixing of the sediment profile due to wave action, animals or any other outside influence must be of concern. Any change in the sediment profile would obviously tend to redistribute the ^{137}Cs within it. Mixing it over a larger part of the profile would tend to reduce the maximum concentration and truncate the ^{137}Cs activity. Kacieszczenko & Banasik (1981) used a model to predict the effects of bioturbation on ^{137}Cs movement and have shown that movement can occur especially in water bodies with low sediment accumulation rates. In general, their study showed that any reworking of sediments tended to broaden the peaks but the key dating points were still evident.

Another facet of the technique is that ^{137}Cs fallout from the atmosphere has been declining since 1963. Thus the last major ^{137}Cs sediment marker in the northern hemishere is now 25 years old (Ritchie & McHenry 1984). The peaks associated with ^{137}Cs fallout from the Chinese and French nuclear tests in 1970/71 are quite small and although not often detected in the northern hemisphere, are more easily detectable in the southern hemisphere (Campbell pers. comm.).

One possible drawback in using the technique is that is does require specialised and expensive equipment. In this study all ^{137}Cs analyses needed to be carried out at the laboratories of ANSTO in New South Wales since suitable equipment was not available in Tasmania. If further extensive analyses are to be carried out in the future in Tasmania then it is suggested that the feasibility of obtaining the necessary detection equipment be investigated.

Finally, even allowing for the difficulties inherent in using the ^{137}Cs technique to date sediments and thus to determine sedimentation rates, it remains a well-established and powerful tool, the use of which permits future sedimentation rates to be predicted without the necessity of having to carry out long and costly manual surveys.

5.3 Heavy metal deposition : a compatible time indicator

Although the major thrust of the work reported in this study has been to determine sedimentation rates in Lindisfarne Bay using the ^{137}Cs technique and thus to provide a sound basis for the prediction of rates of sedimentation, the important issues of pollution in the bay by heavy metals from industrial wastes and bacterial contamination from sewage effluent, both apparently discharged into the Derwent River, have been studied. The ^{137}Cs technique has established certain key dating points such as 1954 when significant quantities of ^{137}Cs entered the atmosphere and 1963 when the nuclear test ban treaty came into force. Thus, core depths can be dated and these dates correlated with concentrations of heavy metals found in the cores.

A remarkable degree of agreement has been shown in this study between key dating points established using the 137Cs technique and the major determining factors affecting pollution in the estuary. On the eastern side of the bay, for example, the metals Cd, Cu, Pb and Zn are all present in cores in significant amounts and that concentrations of these metals peaked at about 1960 and 1971/75 (see Figs 4.14 - 4.19 & 4.27). The 1971/73 reduction almost coincides with the introduction of a new metals recovery process at the EZ works at Risdon in 1974 which EZ claims has reduced by up to 80 percent the amount of heavy metals being discharged to the river, and the 1961 dip in concentration corresponds with the 1 in 100 year flooding of the Derwent River in 1960 which would have resulted in extensive flooding in the estuary and most probably flushing out of some metals. Results of metal analysis of cores K, L and M show, on average for the period 1972 to 1986, reductions in metal levels of 77 percent for Cd, 56 percent for Cu, 22 percent for Pb and 70 percent for Zn which seems to confirm EZ's claim of up to 80 percent reduction in metals being discharged to the river.

On the western side of the bay heavy metals were confined to the surface or near surface of the sediments, but had similiar concentrations as for similiar levels on the eastern side.

5.4 Understanding the deterioration of the bay

This study has identified four major factors associated with deterioraton of the bay, namely:

(1) that the occurrence of rapid sedimentation has been historically linked with indiscriminant land use practices;

(2) that sedimentation of the bay has been derived from several sources, predominantly the catchment of Lindisfarne Bay, but also to a lesser extent the catchment of the Derwent itself and as a result of tidal and wind induced currents;

(3) that the bay is heavily polluted with heavy metals, now buried under a deep layer of sediment and thus presenting problems for removal; and

(4) that the bay is also polluted with bacteria from sewage effluents to the extent that primary contact should not be encouraged until full secondary treatment of effluent occurs.

This study maintains that a firm grasp of the causes of sedimentation leading to the deterioration of the bay is essential before any efforts can be made to successfully rehabilitate the bay.

The Clarence Council commissioned a 10 week study of Lindisfarne and Geilston Bays in late 1987 following successful lobbying by the Lindisfarne Bay Beautification Committee. It is instructive to examine the recommendations of the commisssioned study in light of new data presented in this thesis. The objective of the study was:

> to carry out the necessary investigations to determine a programme of works which would be required to rehabilitate Lindisfarne and Geilston Bays to a stage where normal recreational use and full public enjoyment can be resumed.
>
> (Lewis & Duvivier 1988)

Initial results of ^{137}Cs analysis and heavy metal concentrations forming part of this project were furnished to the consultants in the form of a small report by subconsultancy. Results provided to the consultants came from cores K, L, M, ~~N and O.~~ However, a thorough examination and interpretation in association with later bay and catchment samples had not at that time been undertaken.

The consultants report, following investigations carried out over a ten week period in accordance with the terms of reference, outlined a number of measures available to the Council to tackle the sedimentation problem. The executive summary of that report outlined six points which are stated and discussed below.

> (1)The water quality in the Bays is almost certaintly inferior to the standards given in the Tasmania Department of Environment guidelines for bathing and other recreations which involve frequent direct contact with the water ....therefore it is recommended that the Council should discourage primary contact recreation in the waters of Lindisfarne and Geilston Bays
>
> (Lewis & Duvivier 1988).

This recommendation, although based on only six samples in Lindisfarne Bay during 1987 and also on results of bacterial levels from other parts of the river as part of the Tasmanian Department of Environment Derwent River Monitoring Program, is in conformity with the findings of this thesis. The extent of water pollution borne out in this study however has been by an examination of the complete results of bacterial levels from Lindisfarne Bay for the period 1982-1987 (Fig 3.10). The extent of bacterial pollution by sewage is such that primary contact usage is not recommended.

> (2) Water in the bays is exchanged with water in the Derwent Estuary four times on almost every day. Therefore deterioration of the conditions were caused mainly by human intervention in the Derwent catchment area not by surburban development around each bay. Therefore Council has no control over the marine environment and can only usefully consider works to improve the appearance of the shoreline.
>
> (Lewis & Duvivier 1988)

In asserting that deterioration of the conditions has been caused mainly by human intervention in the Derwent catchment area, the consultants are ignoring the contribution from within the catchment area of the bays themselves. Results of ^{137}Cs analysis from Natone Hill and grainsize analysis of sediments within the bay, which were unavailable at the time of the consultants report, indicate that active erosion in the bay catchment area is occurring. Council does have some control over the land management of Natone Hill and could usefully consider management options such as reducing fire frequency and replacing it by cutting of vegetation where necessary; Council should also discourage or even ban off-road vehicles in the area.

Secondly this summary item appears to oversimplify the situation greatly and ignores the complex processes involved with sedimentation of a bay area. The statement that 'water in the bays is exchanged with water in the Derwent Estuary four times on almost every day' appears to be based at least in part on a loose interpretation of salinity movements in Lindisfarne and Geilston Bays. The data used by Lewis and Duvivier shows a very large scatter and so there is considerable uncertainty in the observed salinity gradient leading to further uncertainty in the estimated exchange ratio of freshwater with salt water.

> (3) The bays are probably silting up quite rapidly. Available information suggests that the bays will be almost completely filled with mud in one to two centuries. It is recommended that very well controlled surveys be made now and in say 5 years time to determine the magnitude of this problem.
> (Lewis & Duvivier 1988)

This third point, presumably based on initial ^{137}Cs results forwarded to the consultants, makes a very simplified interpretation of sedimentation occurring in the bay. From measurements of ^{137}Cs deposition, the eastern side of the bay has shown a rate of accumulation of sediment of between 2.7 and 3.3 cm/yr, assuming a uniform rate of sedimentation. However, this is not the case at the western side of the bay. The movement of sediment within this small bay is complex as indicated by the levels of ^{137}Cs found in some cores, and it should be noted that currents in the bay are often wind induced. Further, as sediment deposition extends further out into the bay, larger amounts of sedimentary material will be required to achieve the same rate of deposition as has been experienced in the head of the bay , such a statement being based on the reasoning that a larger area requires more material. To suggest that ' the bays will almost be completely filled with mud in 1 to 2 centuries' appears to be an exaggeration. As well, the ^{137}Cs technique provides information on rates of sedimentation thus obviating the need for long and costly surveys 'in five years time'. In the 18 years since the ^{137}Cs technique was first used, it has received international recognition and reports have been published around the world which have used the distribution of fallout of ^{137}Cs in freshwater, marine and valley sediments to estimate sediment accumulation rates (McHenry & Ritchie 1984). The ability to estimate sediment accumulation rates without having to return to the same area and make further measurement at later times is the major advantage of the ^{137}Cs technique.

> (4) ...given the proximity to housing and the need to discourage primary contact watersports it would be appropriate to encourage the moorings of pleasure craft in the Bays and the provision of the related facilities.
> (Lewis & Duvivier 1988)

This point appears to be a subjective assessment of the future of the bay based on poor water quality and the assumption that the water quality cannot be improved in the future and beaches cannot be re-established.

(5) As required by the terms of reference a programme of works to dredge (remove) the intertidal mudflats and tidy up the shorelines is tentatively suggested to improve the appearance of the Bays.This would cost in the order of $300,000. It is felt that significant development to encourage pleasure craft moorings are likely then (sic) the works would be redundant. It is therefore considered that the first decision by Council must make is either (a) to encourage the development of pleasure craft moorings in one or both bays; or (b) to manage the shores of one or both bays as parkland and take administrative actions to suppress development close to shore; and

(6) In areas where the decision to develop is taken, it is recommended that an outline plan for the phased developments of the appropriate facilities should be prepared. In areas where the decision to suppress development is taken the plan for the necessary works to improve the appearance should be prepared jointly by the parks department and a coastal engineer.

(Lewis & Duvivier 1988)

These two summary items present the management authority, the Clarence Council, with options for a works programme required to rehabilitate the two bays examined, based on conclusions reached by the consultants. The major conclusion reached, although not clearly stated, suggests that the re-establishment of sandy beaches, which is the bottom line of the Lindisfarne Bay Beautification Committee, is not possible. It is based on an interpretation of tidal dynamics in the estuary and states that the waters of the bays are exchanged four times on almost every day and that therefore deterioration of the conditions has mainly been brought about by human intervention in the whole Derwent catchment and not surburban development around Lindisfarne and Geilston Bays themselves. Although bay waters may be exchanged each day with tides, this does not necessarily lead to the conclusion that the source of the problem is mainly river oriented. The information presented in this thesis shows that the local catchment is a significant contributor to the problem.

5.5 Management Options

The work reported in this study provides a great deal of information relevant to the causes of sedimentation and poor water quality in Lindisfarne Bay which may be useful in studying the deterioration of the estuary generally. Although it has not been concerned with rehabilitation options for Lindisfarne Bay and surrounding areas, it can provide a sound basis for the making of recommendations for improvement and perhaps for rehabilitation of the whole area.

Firstly improvements or eventual rehabilitation must involve concerted efforts to reduce the deposition rates of sediment, heavy metals and bacteria to acceptable levels. Although EZ appear to be taking measures to reduce heavy metal discharges to the river, whilst Ministerial exemptions from meeting the standards set in the Environmental Protection Act 1973 are allowed, heavy metal pollution will continue. To achieve the objective of reduced heavy metal pollution to the river, the Minister for Environment should enforce pollution control measures and cease the current long term exemption arrangement which many industries in Tasmania currently enjoy. EZ's proposed modernisation program should include comprehensive pollution control measures.

Similarly, sewage treatment works have been exempted from meeting the standards set by the Tasmanian Department of Environment. Bacterial counts in the bay area, taken as part of a monitoring program by the Clarence Council, indicate that standard levels of faecal coliforms are being regularly exceeded and although some improvement had occurred since 1982, the date of commencement of the reticulated sewage system, the area still represents a health risk to primary contact users. Full treatment facilities need to be installed and operational at all treatment plants discharging effluents into the river so as to achieve the desired reduction in faecal pollution.

With respect to sedimentation of the bay, it was found that where ^{137}Cs levels were high, so were the proportions of fine particles. The eastern side of the bay showed high ^{137}Cs levels and a high proportion of small particles whereas the western side of the bay showed low ^{137}Cs levels and lower proportions of fine particles. These results are as expected from the ^{137}Cs technique, because ^{137}Cs is readily absorbed by small particles, and indicate some of the dynamics of sediment movement in the bay.

Measures to restrict the sediment load from entering the bay could include:

(1) prevent further building, roading and development on Natone, Gordon and Pilchers Hill unless substantial measures to minimise erosion and escape of sediment are introduced;

(2) stabilise existing house sites;

(3) review the burning and clearing regime of Natone Hill and Gordons Hill;

(4) forbid the use of off-road vehicles on Natone Hill; and

(5) investigate the installation of silt traps at major stormwater outlets.

After taking the necessary steps to prevent further pollution and sedimentation from occurring, a program of dredging and foreshore beautification could be carried out. Results of heavy metal levels with depth suggests that caution should be taken with the disposal of any dredged material. Dredging by bulldozer and disposal of dredged material to secure land fill could be considered. The material should be treated as toxic waste. Any dredging program should only be considered at low tide and a full investigation of dredging options considered before any works commence.

This study has provided enough material for substantial recommendations for rehabilitation and management of Lindisfarne Bay and its surrounding catchment. It also raises many more questions about the sedimentation and pollution in the bay which will require further investigation beyond the scope of this thesis.

Although this thesis has highlighted the concurrence of the development of an area with sedimentation and pollution problems, it does not necessarily imply that development is incompatible with the retention of the naturalness of a local environment. If one adopts the notion that we as humans live in harmony with, and as stewards of, the environment and not as having dominion over the environment, then the dilemmas and difficulties of equating the development of an area with the retention of its naturalness are diminished.

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APPENDIX A

Oral Histories

A number of local residents were interviewed to assist in establishing the state of the bay prior to the onset of the sediment problem. In approaching this task, contact was firstly made with community groups (Lindisfarne Bay Beautification Committee, Lindisfarne Bay Historical Board) and the local libraries (Lindisfarne, Bellerive and the State Library). The State Library Archives provided many early photographs, some of which have been reproduced in Chapter 2 of the study, and some of which were used in interviews with residents to assist in stimulating past memories of the area.

Who and How interviewed ?

Staff from the Bellerive Library provided an initial list of seven people to approach for information on Lindisfarne Bay and environs. This initial list was put together during a recent library display titled 'Then and Now'. People from the list were contacted and initial discussion held. Some people were of great assistance, while others did not want to be interviewed, or felt that they could not contribute much to the project. Table A1 gives a list of the people from whom some valuable information was obained.

Table A1 : List of people interviewed

Name	*Address*	*Comments*
Bill Davenport	41 Cambgidge Rd Mornington	Lived in Lindisfarne for about 20 years and is currently writing a history of Clarence. Interviewed twice, no taping
Mr & Mrs Ford	Freemasons Home Ballawinnie Rd Lindisfarne	Son of the late Captain Ford who ran the Lindisfarne ferry service; built many houses in the area; interviewed three times; taping
Mr & Mrs Gibson	52 Esplanade Lindisfarne	Long term residents of one of the first houses built in the area; family photo appears in Plate 1.2; member of LIndisfarne Bay Beautification Committee; interviewed once; taped
Mrs Shadwick	Park Rd Lindisfarne	Late husband was a photographer; interviewed once
Shirley Beardsley	117 Derwent Ave Lindisfarne	Foreshore resident; interviewed once
Mr E. Waterworth	Lindisfarne	Foreshore resident; interviewed once

Interview technique

Appointments were made with interviewees by phoning and arranging a suitable time and place, usually in the afternoon in the interviewee's home. A list of questions, shown in Table A.2, were prepared and used as a guide with each interview. Emphasis was given to creating a relaxing atmosphere with people seated.

Where possible and with the permission of the individual, interviewed were taped. A recorder was placed in an unobtrusive location but close enough for good reception. It was not until the interviewee was quite settled that the tape recorder was produced. None of the interviewees objected to being taped, although initially some uneasiness was evident. As the interview progressed, the tape recorder became less obtrusive.

Notes were taken in addition to taping and following each interview, tapes were replayed and further notes taken which in turn have been referred to as 'personal communication'.

Information obtained from each interview varied somewhat however where consistency between interviews occurred, information was taken as being accurate. For example, both the Fords and the Gibsons stated that a beach existed in the northeast corner of the bay. Although photographs obtained don't actually verify this fact, it was taken as being accurate especially with the supporting situation that the nearest street has been names Beach Rd. This general approach (discussion with residents, notes and the use of tapes and photographs) has been used to recreate the original condition of the foreshore of Lindisfarne Bay.

Table A2 List of questions asked of each interviewee

Name Approximate age

Address

Occupation / recreational hobbies

How long have you lived in the area ?

Do you recall what the foreshore used to look like ?

- in particular before 1964 when floating bridge was erected ?
- before landfill ?

Do you remember when sandy beaches started to disintegrate ?

Do you or have you used the beaches or foreshore for recreation ?

How do you feel about having the area rehabilitated ?

An interesting outcome of questions asked was the overwhelming answer to the last question in that much enthusiam was expressed at the possibility of rehabilitation.

APPENDIX B
Coring device

The task at hand was to obtain undisturbed sediment samples from the tidal interface of Lindisfarne bay to a depth of one to two m. The selection of a suitable sampling device became a matter of trial and error. Ninety mm aluminium pipe as used previously for coring at Kingston beach, Tasmania (Goede pers. comm.), was expensive and difficult to obtain so unplasticised polyvinyl chloride (UPVC) drainage pipe was used as a substitute. Also it was desirable not to use a metal corer so as to avoid direct contact between the sampling device and sediments obtained for heavy metal analysis. UPVC pipe was chosen because it was versitile, came with various fittings and was relatively inexpensive. Various lengths of 50 and 90 mm pipe were obtained together with push on and screw cap fittings. Handles were made for both diameter pipes.

The technique employed to obtain the undisturbed core samples, was to place the corer vertically on the sampling site and rotate back and forth by holding the handles whilst at the same time pushing down (Fig B1).

The 50 mm corer proved adequate for obtaining undisturbed core samples to a deep of approximately 2.5 m. At this depth an impervious clay layer was struck which formed an effective bung thus enabling the corer to be removed with sample intact. There was approximately half a metre of compaction of sediment in the corer resulting in 2.0 m. of sediment from a 2.5 m. sampling depth.

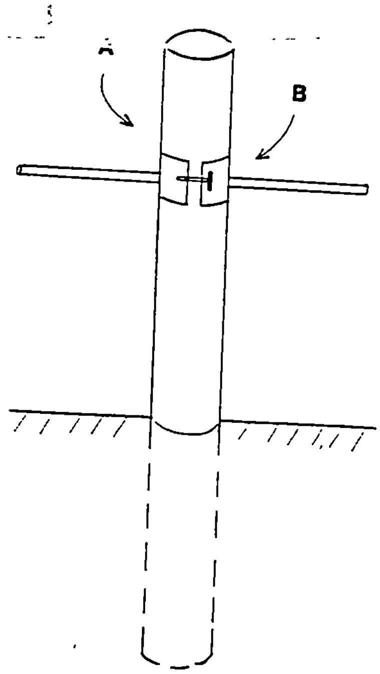

Fig B1 Mechanism to obtain samples by the coring device

A and B indicate refer to the direction of movement

The 90 mm corer was difficult to penetrate to a depth greater than about 1.5 m. because of the shear force required to bore to a greater depth and presumably the increased friction of the larger diameter corer. Also, as the clay layer located at about 2.5 m was not reached and a bung was not formed at the end of the corer, most of the sediment sample was lost during extraction of the corer. Thus an effective seal was required to prevent loss of the sample during removal. It was considered too difficult to insert a sealing device in the bottom of the corer, so the task was approached by forming an effective seal at the top of the corer and therefore reducing gravitational pressure to the top during removal. A push on cap and then a screw cap were used with vaseline on the 90 mm corer. However both devices could not prevent loss of sediment by retention of the samples in the corer on extraction . It appeared that the gravitational force exerted on the samples during extraction required an air tight seal. A testing plug, used in the plumbing industry to test for leaks in a plumbing system, was used . Once the corer was inserted by rotation into the sampling area to the desired depth, the testing plug was inserted and the corer removed. This method was found to be ideal to obtain undisturbed samples to a depths of between1 and 2m.

The 90 mm corer was preferred over the 50 mm corer for the tracer samples because a one kilogram sample was required for each depth profile, in this case 100mm intervals. If the 50 mm corer had been used then twelve samples from each sampling site would have been needed to bulk the samples together to obtain the desired one kilogram sample. The 90 mm corer required only three samples from each site to achieve the required one kilogram sampling size. Also the caesium technique can date sediments only as far back as 1954. With a total sediment depth of approximately 2.5 m. and assuming a uniform sedimentation rate since development, it was believed that sediments from a depth of no more than 1.5 m would be required to establish the location when ^{137}Cs was first introduced into the system, referred to as a modern sediment interface. The 50 mm corer however was used to obtain samples for grainsize analysis to the full depth of the sediment profile (2.5 m.).

Once a sample was obtained, a problem was encountered in the removal of the sample from the corer. In the experimental stage the corer was cut down its length and again at 180° to the original cut thus slicing the corer in half for ease of removal of the sample. The problem with this procedure however was firstly that small particles of PVC created by the cutting process became embedded in the sediment sample therefore contaminating the sample and secondly, replacement of PVC pipes was a costly and wasteful exercise.

Combinations of mechanical and pneumatic pressure were used successfully in an effort to remove the sediment sample from the corer intact. However, at first, a plunger made from 25 mm thick wood, honed to fit neatly into the inside diameter of the 90 mm pipe, with a two metre long dowel handle was tried. This removed some of the sediment however it also compacted the material which make the removal of material very difficult after the first 300 mm. The second method attempted involved pneumatic pressure. A bicycle pump was used which creating air pressure in the corer for removal of sediment from the corer. This method was successful until the sample was about half removed at which time an air leak formed. It was at this point in the experimental trial that the two methods thus far outlined were used in combination. The pumping technique removed the initial sediment from the corer then the wooden plunger removed the remainder of the sample (Fig B2) resulting in minimal compaction and the extraction of in tact samples of sediment.

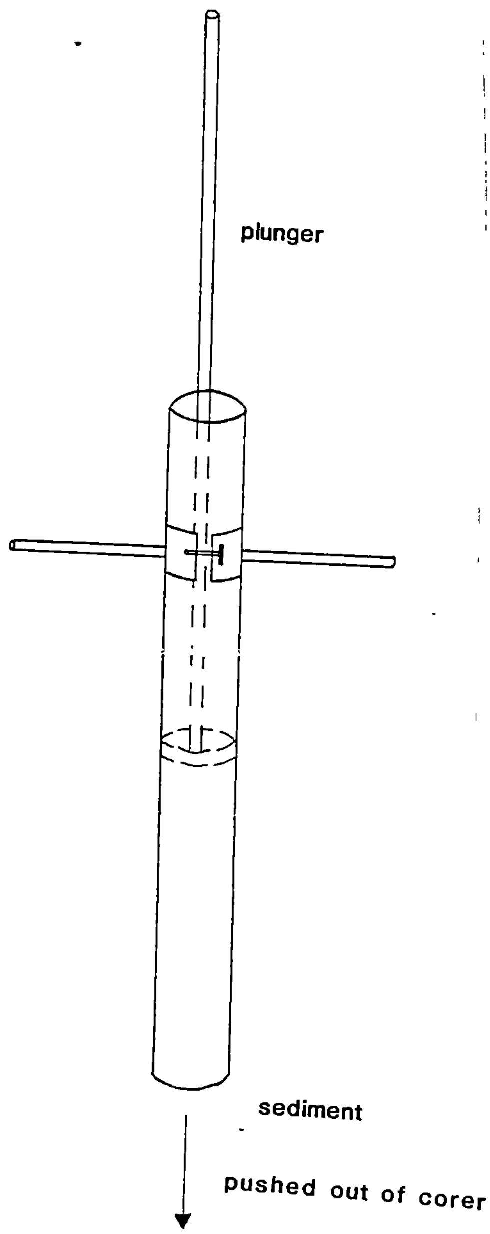

FIG. B2 Removal of sediment from the coring device

In summary, the procedure for sampling sediment in the tidal interface was carried out in the following steps:

(1) Place coring device (90mm diameter for ^{137}Cs and 50mm diameter for grainsize) onto the sampling site and commence rotating into the sediment. Rotate in direction å and ß as shown below in Fig B1;

(2) Upon reaching desired depth, fill remaining space in corer with water, insert and tighten plug;

(3) Extract corer from site and move to shore base;

(4) Using air pressure and mechanical plunger remove sample from corer;

(5) Repeat procedure twice as near as practicable to original coring site (samples for ^{137}Cs analysis only);

(6) For ^{137}Cs samples, divide each sample into 100 mm sections and bulk together the corresponding 100 mm increments of each of the three core samples so as to achieve a minimum dry weight of one kilogram (Plate 4.4). For grainsize samples, subsample 50mm sections from stratifications observed visually from each sample core;

(7) Bag and label ready for transportation to the laboratory for analysis.